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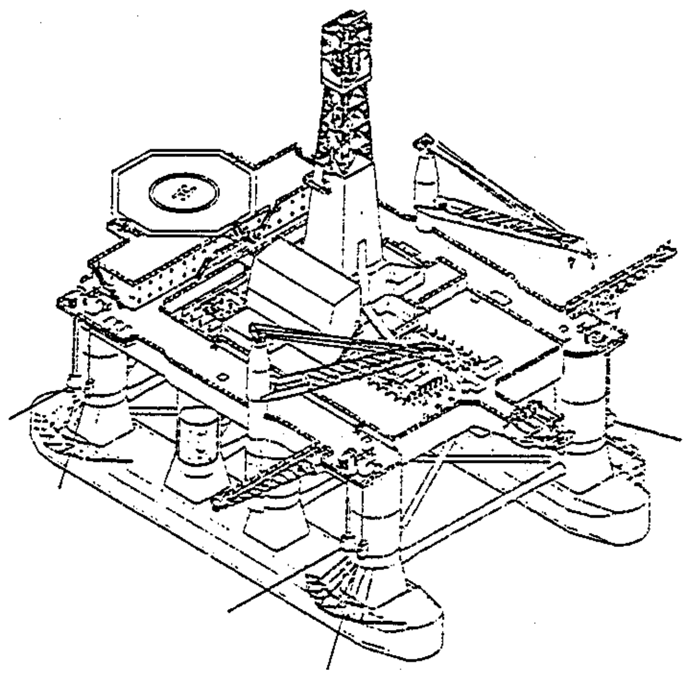
EVALUATION OF SECURING PROCEDURES FOR MOBILE OFFSHORE DRILLING UNITS WHEN THREATENED BY HURRICANES

Final Report



Prepared For:
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REPORT

EVALUATION OF SECURING PROCEDURES FOR MOBILE OFFSHORE DRILLING UNITS WHEN THREATENED BY HURRICANES

(REPORT NO. H3348/NDAI/CAC)

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1. EXECUTIVE SUMMARY

Historically, Mobile Offshore Drilling Units (MODUs) have an excellent performance record for operations in the Gulf of Mexico. An exception to this was Hurricane Andrew during which a significant number of semi-submersibles suffered total mooring failures resulting in catastrophic damage to other structures and pipeline systems. Also during Hurricane Andrew, a jack-up collapsed and drifted approximately 40 miles, and two submersibles moved significant distances. These events prompted the Mineral Management Service (MMS) to commission Noble Denton and Associates, Inc. (NDAI) to examine the factors affecting MODU performance in hurricanes with a particular emphasis on semi-submersible mooring capabilities.

Mooring failures occur fairly frequently[1] but have rarely been the source of catastrophic human and financial losses. The majority of the failures have been limited to single line breakages during mild weather conditions when the consequence of failure is minimal. Hurricane Andrew, in contrast, showed that when conditions in the Gulf of Mexico exceed a MODU's design environment, the consequences of failure are severe, not only for the effected vessels but also for other structures miles away. The potential impact on the offshore pipeline distribution systems was a major factor in initiating this study.

In order to gage the comparative risk of mobile structures in the Gulf of Mexico and other regions, a simple risk assessment was conducted. The Gulf of Mexico historical database that currently exists is inadequate to properly assess the causes of past failures and to determine a proper risk level.* With the data that was available, the following conclusions are drawn. The annual probability of a semi-submersible in the Gulf of Mexico suffering a total mooring system failure (similar to the "*ZANE BARNES*" failure in Hurricane Andrew) was calculated as 1×10^{-2} based on actual historical performance from 1964-1992. It is suspected that a significant numbers of these failures were the result of "human error"† in that the mooring system deployed could not survive a close encounter with even a relatively minor hurricane. The calculated probability, therefore,

* The US Coast Guard currently is required to investigate and maintain a database of significant offshore incidents. As shown in Appendix H, these investigations have been very cursory in nature, and are inadequate for use in risk studies.

† Examples of human error would be: early designs where little was known about the offshore environment, using a mooring system unable to satisfy a site assessment, or use of materials that have exceeded their useful life.

may not represent a true assessment of semi-submersible capabilities and should not be used in a mooring code calibration. Until there is better documentation of incidents, it will be impossible to refine the calculations for the Gulf of Mexico, and one will be forced to use inappropriate data from other areas of the world. Another issue complicating the risk assessment is that semi-submersibles in the Gulf of Mexico have had minimal exposure to extreme weather conditions. Only a small number of semi-submersibles have been subjected to hurricane forces. With the expansion of the deep water development programs in the Gulf of Mexico, the number of semi-submersibles exposed to hurricanes is likely to increase so, based on past trends, one can expect an increase in the number of semi-submersibles that break loose and cause consequential damage.

More data is available for the North Sea, and using a similar methodology to those given above, the annual probability of complete mooring system failure is 5.3×10^{-3}. It is, however, difficult to directly compare North Sea operations with the Gulf of Mexico since the weather conditions are significantly different, and semi-submersibles are manned during storms in the North Sea. The benefit of manning semi-submersibles is that it enables active manipulation of the mooring system to reduce the loads in the mooring lines. This has successfully reduced the number of semi-submersibles suffering a total mooring system failure in the North Sea to one since 1981. In the Gulf of Mexico, MODUs have traditionally been evacuated prior to a hurricane. Some experts have suggested that evacuation of semi-submersibles with onsetting heavy weather may actually increase the probability of human loss, but because of litigation concerns, manning of MODUs in hurricanes is not a viable option.*

Other types of MODUs besides semi-submersibles can become adrift in hurricanes and threaten structures and pipelines (e.g., the jack-up, "*MARLIN 3*", in Hurricane Andrew), but they have a significantly lower probability of suffering such failures (e.g., 1.3×10^{-3} for jack-ups) when compared with semi-submersibles. Consequentially, a correspondingly smaller portion of this report is devoted to them.

* There have been hurricanes that have not hit any offshore structures but which have been responsible for loss of life during evacuation and abandonment. Emergency evacuation, by crew boat, helicopter or by lifeboats moving off location, all have potentially high risks associated with them.

RECOMMENDATIONS

The effect of various factors on mooring system performance were examined with the aim of reducing the chance of future mooring failures. The most important factor was that mooring systems deployed by the drilling contractors must be suitable, as determined by the latest state-of-the-art technology,* and used within their operational limits. While mooring technology has been continually improving over the last 30 years, current practices within the industry have not fully incorporated these changes. Examples of different interpretations of mooring analysis procedures are discussed in Appendix D, but one that needs highlighting is the use of low frequency motions. As semi-submersible sizes get bigger, the contribution from low frequency motions becomes a significant portion of total mooring line tensions. Many analyses done today, however, either totally neglect or inaccurately account for these motions.

Two other issues that should be employed when assessing a semi-submersible's operational limits are a requirement for redundancy and that shallow water, as well as deep water, conditions be examined. Redundancy can be vital in preventing a single line failure from cascading into a total system failure during severe conditions.† It also may be prudent since experience has shown that many mooring line failures occur well below the rated break strength of the line. A redundancy requirement would increase the minimum design criteria in the new API RP which, as discussed in Section 4, may be warranted from the minimal information available on Hurricane Andrew. Analyses in Section 5 demonstrate that semi-submersibles' design limits are as restrictive in shallow water as deep water, and operational manuals should reflect this.

Efforts were made to assess stacking locations that would reduce both the probability of mooring failures and the probability of collisions should such a failure occur. The locations resulting in the most significant reduction were in deep water (1000 to 2000 feet) and 40 miles away from the nearest platform. It is realized that there are few, if any, of these locations available that are suitably close to logistical bases. For this reason, it may be best to stack semi-submersibles, whenever possible, ballasted on the bottom and close to shore. Vessels stacked in this manner should be ballasted to the

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* The new API Stationkeeping Recommended Practices (RP) recently released in draft form best represents the current state-of-the-art in mooring technology.

† Currently, the new API RP requires a one-line damage analysis when operating in close proximity to other structures. When operating in isolated areas, there is no redundancy requirement.

maximum extent possible, but research shows a bearing pressure of at least 250 psf is necessary to minimize the chance of sliding off location.

To improve future studies such as this, it is recommended that all MODU incidents and near incidents* be investigated in detail, so as to determine the factors contributing to the incident. This will allow the lessons learned to be shared within the industry. Also, a database should be established containing the results of these investigations to aid in calibrating industry standard practices and thus, reduce the probability of future failures. The present system of investigation is inadequate as insufficient information is accumulated too late to allow any theoretical/practical calibration. It is only through such calibration that the codes can be enhanced and safety improved.

On the following page, a brief abstract covering each section of the report is given.

* Near incidents would be those which may have involved a small monetary loss, but could have possibly cascaded into a major catastrophe. An example of a near miss would be the "*OCEAN NEW ERA*" in Hurricane Andrew where a small amount of anchor drag may have prevented the vessel from breaking adrift. As much can be learned from near misses as significant failures.

SECTION ABSTRACT

Section 2. Introduction:

Outlines a brief chronology of changes in design philosophy surrounding semi-submersibles operating both in the Gulf of Mexico and the North Sea.

Section 3. History of Mooring Failures:

Examines the events of Hurricane Andrew in an attempt to predict factors affecting the failures that occurred and the moorings that survived intact. The history of mooring failures and lessons learned over the past 30 years are reviewed both in the Gulf of Mexico and other regions of the world.

Section 4. Mooring Design Criteria:

Recommends the use of the proposed API Recommend Practices (RP) for Station Keeping, but describes some improvements and possible short comings in the recommended practices. Implementation of this RP should greatly increase the level of safety for semi-submersibles operating in the Gulf of Mexico. A brief comparison of the API RP and DNV's POSMOOR mooring code for MODUs is made, with further details shown in Appendix D (Commentary on Mooring Analysis Components) and Appendix F (Comparison of API and DNV Mooring Procedures). In addition, a synopsis of the current industry efforts to develop a reliability based mooring code is given, as well as areas in this regard which require further research.

Section 5. Positioning of MODUs:

Explores the criteria for selecting a mooring site, the effects of soil conditions and water depth on mooring system performance. Hurricane Andrew is used as a source of data on anchor performance in relation to its effect on the overall mooring system performance, but much of the data is contradictory, indicating a need for further research. The computer simulation model (created by the University of California, Berkeley) is used to examine the effect of the proximity of structures and past hurricane paths to a MODU on the probability of the MODU colliding with another structure.

Section 6. Jack-ups in Hurricanes:

Reviews the different issues affecting a jack-up's structural integrity in a hurricane and possible consequences should a failure occur.

Section 7-8. Submersibles and Other Moored Equipment:

Briefly outlines the performance characteristics of these vessels during hurricanes.

2. INTRODUCTION

Hurricane Andrew caused more damage to offshore structures than any other hurricane in history, but it was not this alone that has caused the concern. In most of the previous hurricanes responsible for extensive damage, individual platforms had failed, but there had never been the level of interaction between failures that there was during hurricane Andrew. In Andrew, there were platforms knocked over by drifting Mobile Offshore Drilling Units (MODUs), pipelines being moved by wave action, and possibly damaging attached structures; pipelines moved by MODUs dragging the seafloor as they drifted around; and major oil distribution systems threatened by floating equipment. Figure 2.1 illustrates the magnitude of distance a failed MODU can travel and the range of structures that are potentially affected. After a quick review of the effects of Andrew, it became apparent that one of the major areas of concern was that semi-submersibles were breaking adrift more readily than had been anticipated by the regulators. The number of semi-submersible failures relative to other types of MODUs during Hurricane Andrew is shown below in Table 2.1. The problem was not confined to the older units where the expectation of performance may have changed with time, but it was the new designs that were responsible for much of the damage and threats. As a result of this, the Minerals Management Service commissioned Noble Denton and Associates, Inc. and the University of California, Berkeley to study the history and performance of MODUs during hurricanes, with particular reference to semi-submersibles. The report that follows presents the result of this study.

Table 2.1 MODU Failures in Hurricane Andrew

Rig Type	In Gulf	Exposed	Moved
Jack-ups	91	28	1
Semi-submersibles	10	8	3
Submersibles	10	8	2
Drillships	-	-	-

2.1 REPORT STRUCTURE

The report is structured in such a way that the main report is a stand alone document that covers the important information and findings of the study, but often in a summarized form. The details and commentary are contained within the appendices. Also contained in the appendices is additional information that may be of general assistance to the reader. For example, Appendix B contains a glossary of terms used in mooring analyses, and Appendix D contains a description of the various components (and their significance) that make up a mooring analysis. Most of the main report concerns the use, analysis, and experience with semi-submersibles, these being the primary thrust of the study, but also included is a discussion of the history and experience with jack-ups along with a very limited discussion of submersibles and other floating equipment.

The work completed by University of California, Berkeley in support of this project:

- *Development and Verification of a Computer Simulation Model for Evaluation of Sitting Strategies for Mobile Drilling Units in Hurricanes*, and
- *Evacuation of Offshore Platforms Due to Severe Weather Conditions*

are included with this report as separate enclosures.

2.2 HISTORICAL BACKGROUND TO MODU DESIGN

It may be constructive to start by explaining some of the evolution of MODUs, and some of the factors that have affected their design. MODUs have been successfully operating around the world for many years, in many different climates. Some of the earliest cases of exposed offshore operations were in the Gulf of Mexico, but little was known about the effects of hurricanes. Even after the early hurricanes that did significant damage, and caused the design premises to start to change, there was still a prevalent view that hurricanes were unusual events and the probability of impact with a specific rig was small.

The North Sea development caused a change in thinking about operations because of the completely different environment form the Gulf of Mexico: whereas the Gulf of Mexico was generally benign with occasionally severe hurricanes, the norm in the North Sea was large waves and strong winds, with occasional periods of calm. Indeed it is remarkable, when one considers some of what happened during the early North Sea operations, that there were so few disastrous failures.*

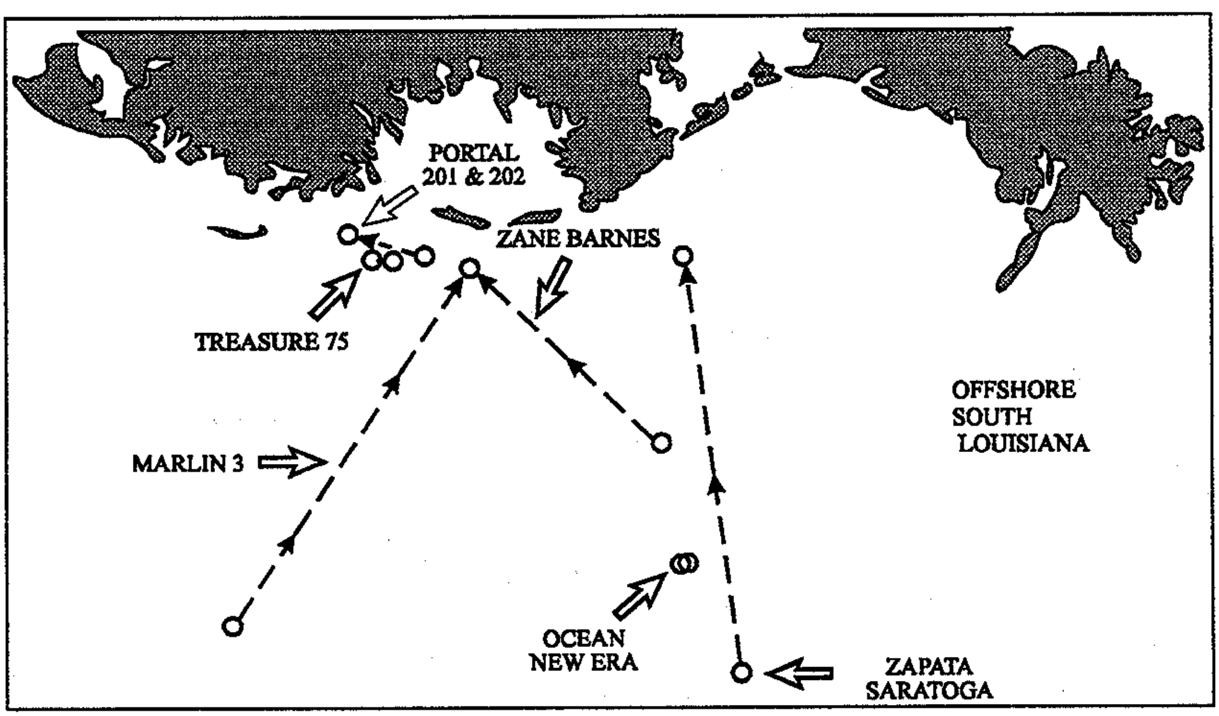
It was as a consequence of the early North Sea experiences, and Hurricane Hilda (1964) in the Gulf of Mexico, that the evolutionary process started with MODUs. While drillships and semi-submersible drilling units had existed before this time, they had tended to be either modified submersibles, or converted barges, and had very crude

* It is reported that during one storm the waves got so big, by comparison to the unit's air gap, and what was expected, that the *"GULFTIDE"* was picked up, moved a few feet, and set back down again. While the story may be apocryphal, it does indicate that the units were operating in an environment that was absolutely new to them.

mooring systems. The jack-ups that existed tended to be more advanced, being purpose-designed and built. During the middle and late 1960s, the industry boomed. Meteorological data was becoming available from North Sea experiences, and designers were faced with even higher wave heights and wind speeds to be used in the analysis of their units, which were then submitted for class approval to the newly compiled class rules for MODUs.[2] The result was designs evolved that could withstand the rigors of a North Sea winter, and a Gulf of Mexico hurricane. Since that time the designs of MODUs have improved, in many cases to keep pace with changes in required water depth and drilling capabilities, but also to account for changes in the expected storm survival requirements.

As more environmental data became available, it became apparent that the earlier North Sea MODUs were no longer suitable for operations there, so they were moved out to more benign areas and to the Gulf of Mexico. The result was that as the North Sea fleet was generally newer, the Gulf of Mexico fleet tended to consist of older units. In the Gulf of Mexico, this has had surprisingly little apparent effect on the failure rate of MODUs although the reasoning may be concerned as much with the probability of being hit by a hurricane as by the survival capabilities.

Figure 2.1 MODU Movement During Hurricane Andrew



3. HISTORY OF MOORING FAILURES

Worldwide, semi-submersibles have a long record of operations which provide a great deal of historical information. Modern semi-submersibles have been operating successfully in the Gulf of Mexico since the early 1960s. The first semi-submersibles, "BLUE WATER 1" and "OCEAN DRILLER", were affected by Hurricane Hilda in 1964 shortly after commencing operations. Hilda capsized "BLUE WATER 1" and broke the moorings of "OCEAN DRILLER" causing it to drift 15 miles. Since Hurricane Hilda and prior to Hurricane Andrew, there have been few exposures of moored semi-submersibles to hurricane conditions, and therefore, it is difficult to gain a full perspective from a historical review only. From the limited experience there has been, little effort had been made to globally examine the factors affecting past mooring failures in the U.S. waters, but as a result of mooring damage to North Sea MODUs in the winters of 1990-92, there has been increase in studies commissioned in that region. If future improvements are to be made, incidents must be investigated in detail immediately, and any lessons learned shared within the industry. This is particularly important in the Gulf of Mexico region with its dense population of platforms.

This section will primarily examine the historical performance of moored semi-submersibles under hurricane conditions. While there are other moored vessels operating in the Gulf of Mexico, it is the damaged caused by drifting semi-submersibles during Hurricane Andrew that prompted this study to be undertaken. Vessels such as drill barges, tend to operate close to shore and move inland in the event of a hurricane. They are not typically designed to survive offshore in a hurricane. Drillships, which possess similar characteristics to semi-submersibles, have not had the same, albeit limited, exposure to hurricane conditions in the Gulf and consequently, were not examined. The weather in the Gulf is mostly benign, and only the occasional hurricane produces the majority of weather that approaches the design limitations of semi-submersibles: thus this study focused primarily on hurricanes survival rather than winter storm survival.

3.1 GULF OF MEXICO

3.1.1 Past Hurricanes

Prior to Hurricane Andrew, mooring failures causing MODUs to be set adrift rarely occurred in the Gulf of Mexico, and with those that did resulted in no significant damage.

This record may lead some to conclude that past practices were conservative and thus validated. A survey of past hurricanes and MODU positions has found that the lack of accidents should instead be credited to a lack of exposure to extreme weather conditions, and therefore, it is difficult to draw any substantial conclusions on the reliability of past Gulf of Mexico operations.

As part of this study, past hurricanes of category 3 and above contained in the list below were investigated with respect to the proximity of the path to semi-submersible positions.

Table 3.1

Hurricanes Evaluated		
Name	Date	Cat
Hilda	Sept 1964	4
Betsy	Sept 1965	4
Camille	Aug 1969	5
Celia	Aug 1970	3
Edith	Sept 1971	5
Carmen	Aug 1974	4
Eloise	Sept 1975	3
Frederic	Sept 1979	4
Allen	Aug 1980	5
Alecia	Aug 1983	3
Elena	Sept 1985	3
Andrew	Aug 1992	4

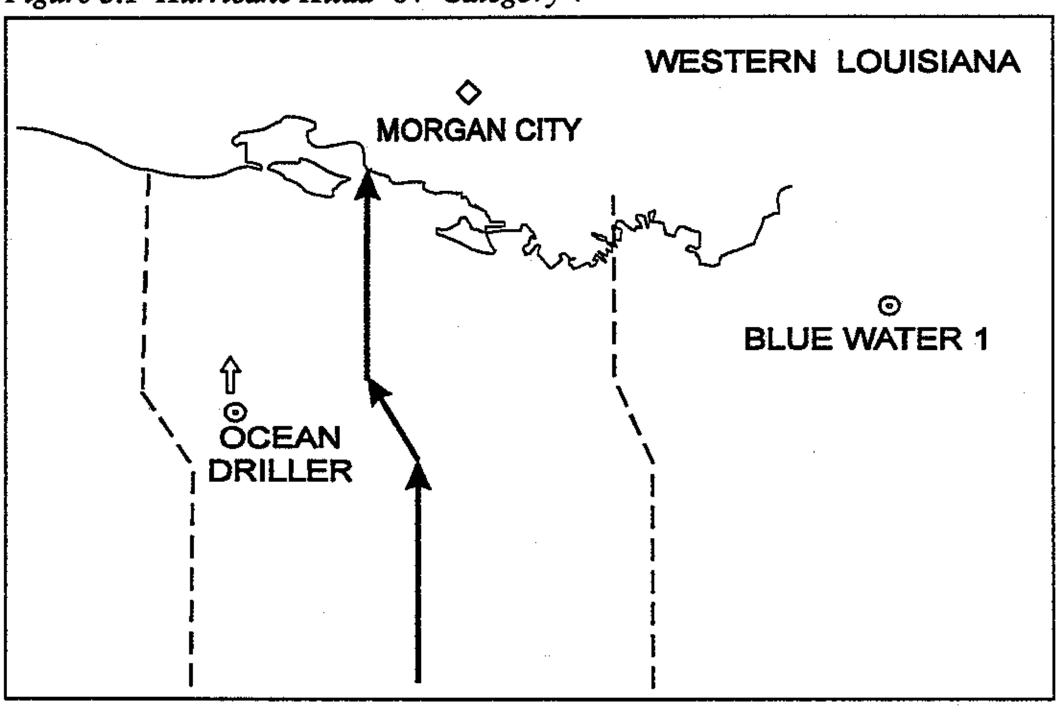
From 1964, only three hurricanes; Hilda '64, Elena '85, and Andrew '92, passed within 50 miles of any semi-submersible positions. In each of these hurricanes, storm induced failures resulted in MODUs becoming adrift. The following chronology of past hurricanes summarizes the results of this study, and diagrams illustrating the results are shown in Figures 2.1 through 2.11. For each storm, the dashed line represents 50 miles on either side of the hurricane's path and indicates the maximum extent of extreme wind forces. Past MODU positions for this study were obtained from trade publications such as *Offshore Rig Locator, Offshore Magazine, The Oil and Gas Journal, Offshore Data Services,* etc..

It should be noted that semi-submersibles tend to operate in the same general geographic areas during any given time period rather than being evenly distributed throughout the Gulf of Mexico. As a result, the overall probability of exposure to a hurricane is reduced. When a hurricane does encounter a group of semi-submersibles, as in Andrew, more are exposed to this one weather event, and thus a high number of failures result. This leads to bunches of failures separated by a large number of "no accident" years, and consequently experience is much more limited than expected. In other words, 10 rigs operating in a clump for one year does not necessarily represent 10 rig years of safe operation in a risk analysis.

Hilda '64

Hurricane Hilda was the first hurricane which exposed modern moored semi-submersibles to hurricane forces. Just prior to Hilda, there were three moored drilling rigs off Louisiana. The most fortunate was the *"GLOMAR 4"*, a drillship, which moved quickly inshore to Lake Charles where it rode out the storm. The *"BLUE WATER 1"*, the first industry's semi-submersible, was some 100 miles to the east of the path of taken by the eye of the storm. After the storm, the *"BLUE WATER 1"* was found floating upside down in the middle of its moorings due to a structural failure caused by tornadoes spawned from the hurricane. The *"OCEAN DRILLER"* located about 30 miles east of the path, broke two of nine chains and dragged the rest for 10 miles. A crew of 14 safely rode out the storm.[3] Industry practice in the Gulf of Mexico is to evacuate offshore rigs during hurricanes, and this was the only documented instance in the Gulf of Mexico of personnel remaining onboard a semi-submersible during a hurricane of this strength.

Figure 3.1 Hurricane Hilda '64 Category 4



Betsy '65

During Betsy, a category 4 storm, there were no semi-submersibles located in the Gulf as indicated by the trade publications. The *"BLUE WATER 1"*, which was in the processes of being salvaged at the time, drifted during the hurricane and collided with the West Delta Block 134A platform.

Camille '69

While this was the strongest hurricane the offshore industry had experienced to date, there was sufficient warning to allow all MODUs to move to sheltered water prior to the storm's approach. During this time period, MODUs operated fairly close to shore, and in the event of a hurricane, they moved inland to sheltered waters as standard procedure. This was especially fortunate during Camille since several semi-submersibles were, prior to moving, working in areas that Camille passed through.

A problem arises when moving the semi-submersibles in to shore. Like a ship, securing a semi-submersible to withstand hurricane forces is extremely difficult. They tend to break adrift and run aground, occasionally colliding with other vessels. An example of this was during Hurricane Chantal in 1989: there two semi-submersibles grounded and received minor damage from collisions when they were moored in Galveston's harbor.

Other Hurricanes

As shown in Figures 2.4 through 2.9, there were no semi-submersibles located in the path of the following hurricanes: Edith '71, Carmen '74, Eloise '75, Frederic '79, Allen '80 and Alecia '83.

Elena '85

Elena initially moved toward the western coast of Florida, turned around, and ran parallel with the Panhandle until it hit landfall in Western Louisiana. There were two semi-submersibles, *"ZAPATA YORKTOWN"* and *"OCEAN ROVER"*, working the Destin Dome region at the time, and both were set adrift by the storm.[4] Due to the distance to the nearest port, these units were unable to move inland prior to the hurricane. No damage resulted from either of these incidents which could be attributed to the lack of offshore structures in the Destin Dome region.

It is also interesting to note that only Noble Denton Accident Database contained a complete record of mooring incidents during Hurricane Elena. The Worldwide Offshore Accident Databank lists the *"ZAPATA YORKTOWN's"* mooring failures, but it does not reference the *"OCEAN ROVER"*. The opposite holds true for the Offshore Data Services

Database. Neither of these incidents were investigated nor documented by the U.S. Coast Guard. Such conflicting records can make risk studies based on actuarial data difficult.

Interim Conclusions:

- Historically, semi-submersibles' lack of exposure to hurricanes is the principal factor contributing to the small number of mooring failures.
- As MODUs work further offshore in deeper waters, it is no longer practical for them to move inland during the onset of a hurricane.
- Towing large 3rd and 4th generation semi-submersibles to port is seen by the industry as a high risk, and several are self-propelled and have a draft deeper than available port water depths.
- MODUs moored in sheltered waters are subject to mooring failures, collision, and grounding.
- During Elena, the lack of damage from drifting MODUs can be attributed to the failures occurring in a stark area off the coast of Florida.
- A better historical database needs to be maintained of past MODU incidents particularly the lower dollar damage incidents that could have escalated.

3.1.2 Hurricane Andrew

Andrew passed through the central South Timbalier region offshore Louisiana and caused the most extensive damage to both fixed platforms and semi-submersibles to date. With a total of eight semi-submersibles located within the path of the storm, three rigs broke or dragged their moorings and damaged various platforms and pipelines. These rigs were:

> *"ZANE BARNES"*, which broke all 8 mooring lines, drifted approximately 30 miles to the north-west and toppled a platform, interfered with several pipelines (some of which may have been damaged prior to the arrival of the *"ZANE BARNES"*) and collided with a second platform (which may also have been damaged prior to its arrival).
>
> *"ZAPATA SARATOGA"*, broke 7 mooring lines and dragged one anchor. It drifted some 40 miles to the north-east and passed dangerously close to the Louisiana Offshore Oil Port (LOOP).
>
> *"TREASURE 75"*, is believed to have been ballasted on the seafloor with four anchors deployed prior to Hurricane Andrew. By the time Andrew had passed,

she had dragged along the bottom for approximately 4 miles and ruptured a large Texaco pipeline spilling 2000 BBL of oil.[5] This incident was one of the worst spills during Hurricane Andrew.

Data on all eight rigs, such as mooring systems and hindcast conditions[6] experienced during Hurricane Andrew, are included on the following page in Table 3.2.

Table 3.2 Semi-Submersibles Near Hurricane Andrew

Rig Name	Type/ Generation	Size (LT)	Location	Condition	Water Depth	Wind/Wave Encountered	Mooring System: Chain	Mooring System: Wire	Anchor Type
Zane Barnes	Trendsetter 4th Gen.	52843	Grand Isle Blk 87	Stacked	167 ft	Wind = 90 kts Hs = 38 ft	8 x 2000ft 3 9/16" ORQ +20% CBS 1600 kips	9900 ft 3 1/2" CBS 1400 kips	33 kips Bruce F.F. Mark III
	Damage: Broke all mooring lines, drifted 30 nm								
Zapata Saratoga	SS-2000 2nd Gen.	16490	Miss. Canyon Blk 705	Drilling	845 ft	Wind = 98 kts Hs = 37 ft	8 x 2500 ft 2 3/4" ORQ CBS 889 kips	4500 ft 2 3/4" CBS 695 kips	40 kips Vicinay Offdrill
	Damage: Broke 7 of 8 mooring lines, drifted 50 nm								
Treasure No. 75	Unique 2nd Gen.	40313	South Pelto Blk 7	Stacked	36 ft	Wind = 90 kts Hs = 28 ft	8 x 6500ft 3" ORQ CBS 1044 kips	None	33 kips Unknown
	Damage: Drifted 4 nm, dragged anchors across pipeline								
Ocean New Era	Ocean N. Era 2nd Gen.	14670	Grand Isle Blk 103	Drilling	255 ft	Wind = 113 kts Hs = 41 ft	8 x 5200ft 2 3/4" ORQ CBS 889 kips	None	22 kip Stevpris
	Damage: Anchors dragged 800 ft?								
Ocean America	Ocean Odessey 4th Gen.	42842	Ship Shoal Blk 236	Stacked	140 ft	Wind = 107 kts Hs = 33 ft	8 x 3900ft 3 1/4" ORQ+20% CBS 1450 kips	5600ft 3 1/2" CBS 1250 kips	22 kip Bruce Mark IV
Ocean Voyager	Ocean Victory 2nd Gen.	22600	Ship Shoal Blk 236	Stacked	140 ft	Wind = 107 kts Hs = 33 ft	8 x 5300ft 3" ORQ CBS 1044 kips	None	30 kip LWT
Ocean Endeavor	Ocean Victory 2nd Gen.	22600	Ship Shoal Blk 236	Stacked	140 ft	Wind = 107 kts Hs = 33 ft	8 x 5300ft 3" ORQ CBS 1044 kips	None	30 kip Moorfast
Ocean Ambassador	SS-2000 2nd Gen.	15230	Ship Shoal Blk 221	Stacked	138 ft	Wind = 76 kts Hs = 23 ft	8 x 4000ft 3" ORQ	None	30 kip Baldt

Of the remaining rigs, all were operated by Diamond Offshore at the time. One reportedly dragged her anchors 800 feet while the rest escaped unharmed.

To attempt to discover the cause of these mooring failures, a series of post-incident mooring analyses for four of these semi-submersibles was carried out. Assumptions and results used in these analyses are detailed in Appendix H. This analysis proved to be difficult since information on the condition of the mooring systems at the time of abandonment was not available, with the exception of the *"ZANE BARNES"*. The U.S. Coast Guard did conduct investigations into each of these incidents, but in each case, details were lacking other than a simple statement of the fact that the failures were caused by storm overloading. Copies of these investigations are included in Appendix H. With reasonable assumptions, the following results provide an indication into possible causes of the failures.

ZANE BARNES

Of all the rigs examined, the *"ZANE BARNES"* is the only one for which the details of the mooring system deployed are known. The exact orientation of the rig, line scope, and line tension at time of abandonment enabled a detailed mooring analysis to be conducted. The outcome of the analysis showed that in the meteorological condition during Andrew, the rig's calculated line tensions exceeded the line catalog break strength by over 50 percent.

With the system deployed in Andrew, the line scope was sufficient to meet the required safety factors using the 99.9% non-exceedence in the API Recommended Practice (RP) 2P.[7] Within the industry, it is now generally recognized that this criteria is insufficient to assure a reasonable level of safety. API is updating its mooring analysis recommended practices[8] and increasing the weather design criteria to a 5 year return period for isolated areas and 10 years when operating in close proximity to other structures. The new API RP is discussed further in Section 3. Using this new criteria, the line scope used was insufficient to meet quasi-static or dynamic safety factor for a 5 year return period. Two primary factors would have increased the mooring capability: a deeper water location and a longer scope of line. The shallow water depth leads to a stiffer mooring system that is not well suited to resist the potentially large wave frequency motions and large low frequency motions.*

Due to the short line scope, calculations showed a large amount of anchor uplift force indicating the anchors should have dragged. In current mooring practices,[8] anchor drag is assumed to redistribute mooring line tensions and to help prevent mooring line breakage. In this case, the anchors did not drag and the mooring lines broke. Anchor drag and its effect on mooring system integrity is discussed in depth in Section 4 of this report.

It is impractical to predict that the *"ZANE BARNES"* would have survived had it been moored in accordance with the new API RP 5 year criteria; however, it is reasonable to suggest that if it had, its chances of surviving Hurricane Andrew would have been significantly increased. Had the vessel been moored to the 10 year API criteria, even though Hurricane Andrew exceed these meteorological limits, it is most probable that the *"ZANE BARNES"* would have survived because of the non-collinearity of the weather directions between wind, wave, and current.

ZAPATA SARATOGA

The *"ZAPATA SARATOGA"* was drilling in approximately 850 feet of water depth just prior to Hurricane Andrew. Since the line scope of the mooring system is unknown, a series of different line scopes was analyzed quasi-statically and results are shown in Appendix G. There are assumptions and points of error in any mooring analysis, and it is difficult to predict the actual level of tensions. The analysis values do provide data for comparison and a general understanding of the magnitude of tensions experienced. While all cases evaluated produced tensions near the catalog break strength (CBS), the worst case tensions of those evaluated were produced by the 2600 feet line scope case. These tensions were over 25 percent higher than the 4000 feet of scope case.

For comparison, the 2600 feet line scope was further examined under API criteria. The post incident analysis found that the 2600 feet line scope satisfied the 5 year criteria for isolated operations, but did not satisfy the more severe 10 year or 5 year with one line damaged requirement.† Had the rig actually used a mooring line scope of 2600 feet, a

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* Wave and low frequency motions are applied to the vessel, almost regardless of the mean mooring line loads, consequently, in a stiff mooring system, a given wave induced displacement will lead to much higher mooring line loads than will the same displacements applied to a soft mooring system. One way to increase mooring flexibility is to increase the length of mooring line deployed. There are limits: too much line out leads to high bottom friction and ineffective use of the line.

† The 10 year and one-line damage criteria are both required when operating adjacent to other structures. The one-line damage criteria is normally associated with the 10 year criteria.

mooring analysis done to the new API standards would have shown this amount to be sufficient. Barring any material defects leading to premature failure (not necessarily a good assumption, based on past experience with mooring systems), the actual performance suggests that an inadequate amount of line scope may have been used. Since the worst of 3 cases analyzed satisfied the 5 year criteria, but the unit still broke free, there is some suggestion that the criteria for isolated operations should be more severe. If a more stringent criteria was used, a longer scope would have been required.

Again, as with the *"ZANE BARNES"*, it is difficult to demonstrate that a longer scope would have prevented the rig from coming adrift; only that it would have resulted in reduced tensions as compared to the assumed case. A longer scope may have, in fact, been used. Due to these unknowns, this case should not be used to make any conclusive arguments on the proper design criteria for a semi-submersible operating in isolated areas, but only indicates that the criteria for isolated operations should be examined further.

The physical condition of the mooring lines, the manner in which they were deployed, in addition to the line scope, all have an impact on the overall system's performance. There could have been a material defect in the mooring lines undetectable by current inspection standards that waited until this time to cause the failure. The age of the lines alone, without any major material defects, could have affected the actual break strength of the lines. Had a realistic value been used as opposed to the catalog break strength been used in the above cited mooring analysis, the 5 year criteria may have sufficient to show a longer length was required. There are just too many unknowns to draw any hard conclusions. What can be said is that detailed investigations must be made after incidents such as this, in order to gain accurate information so that proper decisions can be made by the industry with regard to the design criteria of semi-submersibles.

OCEAN NEW ERA

Located close to the right side of the storm, it endured the worst of all the Ocean rigs and for this reason, is likely to be the one which suffered anchor drag of 800 feet. A mooring analysis using 3300 feet of line scope indicated that the mooring tensions exceeded the catalog break strength by 7%. If the *"OCEAN NEW ERA's"* anchors did drag, this may have redistributed the line tensions and maintained the actual tension below the actual break strength. In this case, anchor drag may have prevented a mooring line failure. Analysis of this incident is important since it is one where failure might have been but did not. Detailed understanding of these successes is paramount to furthering industry knowledge.

OCEAN VOYAGER

The *"OCEAN VOYAGER"* was stacked in a group with two other Ocean rigs farther to the west of the storm, and was not reported to have received any damage. It experienced far less wind and wave forces than did the *"OCEAN NEW ERA"* and thus, would have been expected to have fared much better. A mooring analysis confirmed this with computed tensions approximately 30 percent below the catalog break strength for a line scope of 3000 feet.

TREASURE 75

The *"TREASURE 75"* was ballasted on the seafloor during Andrew and, therefore, no mooring analysis was conducted. Since the rig did move, it can be assumed that the rig had insufficient ballast onboard to weather the storm. In this condition, the rig can be treated as a submersible, and a discussion of adequate bottom hull pressure for submersibles is briefly discussed in Section 7.

The conclusions drawn in this section are conjectural since details surrounding each event are unknown. Had investigations been conducted and more information been made available, the findings may have been more conclusive. The following interim conclusions are offered from Hurricane Andrew observations.

Interim Conclusions:

- Mooring failures during hurricanes can lead to damage of structures many miles away.
- The current API 2P 99.9% non-exceedance design criteria for MODU moorings is insufficient to prevent mooring failures in hurricanes of similar magnitude as Hurricane Andrew, if they are within 50 miles of the path of the storm.
- The 5 year design criteria proposed in the new API Stationkeeping RP is a more stringent than existing criteria. Based on the minimal information available from Hurricane Andrew, this criteria, however, may be insufficient to preclude mooring failures in another hurricane the size of Andrew.
- Based on a 10 year criteria or a one-line damage requirement combined with the 5 year criteria, it is probable that, barring premature component failure, a semi-

submersible mooring designed to either standard could have survived a direct hit in Hurricane Andrew.

- A small amount of anchor drag can be beneficial in preventing mooring line breakage and further investigation should take place on whether lighter anchors with the ability to drag might be an approximate addition to the criteria.
- Vertical uplift force on an anchor does not always cause the anchors to drag.
- Drag embedement anchors can withstand loads beyond their rated capacity during storms.
- Units stacked on the seafloor should have sufficient hull bottom pressure to prevent movement in hurricanes.
- More detailed investigations should be conducted of all units exposed to a hurricane in order to learn more on preventing future damage. A recommended format for these investigations is contained in Appendix H.

3.1.3 Other Storms

<u>Winter Storm '83</u>

While not a hurricane, a winter storm in 1983 caused a significant amount of difficulty to semi-submersibles operating in the Gulf. Three semi-submersibles were reported to have had anchors slip causing them to move off station. One of these, the *"OCEAN TRAVELER"*, lost its wellhead and BOP. The *"BLUE WATER 4"* suffered at least one mooring line failure, and the *"OCEAN DRILLER"* broke all her moorings and drifted 50 miles before being recovered.[9]

It is storms such as these that are additionally a threat to the riser and wellhead as well as to the survivability of the entire mooring system.* An operational concern to the drilling contractor, in these cases, is to decide when to stop drilling operations and disconnect the riser from the wellhead. Once this is done and the tensions on the mooring line slackened, the rig is capable of weathering much greater wind and wave forces. When the riser is connected, the rig is especially vulnerable, and the potential consequence of failure is larger since it can damage the wellhead or lead to loss of well control.

* In this case, the *"OCEAN DRILLER"* did break loose, but this rig was an early generation semi-submersible prone to failures and has since been decommissioned.

Minor anchor drag is also a concern to equipment such as the wellhead or pipelines in the immediate vicinity of the rig. When such equipment is present, extra care should be taken when setting the anchors to ensure the minimum chance of dragging.

Juan '85

As a relatively low wind strength (category one) hurricane, Juan's importance to semi-submersibles was the lack of warning since it was quick to develop. As with winter storms, it was additionally important to the drilling operations and its effects on the riser system's integrity. The path passed many rigs, but only one floating rig was affected.[*] The drill ship, "*GLOMAR ATLANTIC*", suffered a mooring line failure and damaged the riser before it could be disconnected.[4]

Other mooring system performance data for the Gulf of Mexico in regards to operational capabilities is generally not available. While it is known that single line failures and anchor drag do occur, they are not reported to any regulatory agency nor carried in the media. Many single line failures are associated with anchor placement operations and accepted as part of normal semi-submersible operations.

Interim Conclusions:

- Operators must take prompt action in the case of onsetting heavy weather to prevent damage to the riser and loss of well control.
- Anchor drag can damage nearby subsea structures such as the wellhead and pipelines.

3.2 OTHER REGIONS OF THE WORLD

3.2.1 North Atlantic

Four semi-submersibles conducted exploratory drilling near Georges Bank between 1981 and 1982. Because of the environmental sensitivity of the area, these operations were closely monitored by the Minerals Management Service (MMS). Two of the rigs, the "*ZAPATA SARATOGA*" and "*ROWAN MIDLAND*" suffered a string of mooring failures that caused the MMS to investigate the causes of the failures.[10] A summary of their findings are as follows.

ZAPATA SARATOGA

[*] The jack-up "*PENROD 61*" collapsed during Juan, and then collided with the sister rig "*PENROD 60*".

The *"ZAPATA SARATOGA"* suffered six mooring line failures; two during the initial anchor placement and four during a 3 week period in November. An analysis conducted for the MMS revealed the mooring system deployed was unable to meet the required safety factors in API RP 2P. The *"ZAPATA SARATOGA"*, uses a combination chain and wire system,* and after these failures, a shorter scope of line was used replacing the wire in the catenary with chain. The heavier chain enabled more of the load to be absorbed by the catenary of the mooring line instead of the load being absorbed by the stretch of the wire and allowed the rig to meet the API prescribed safety factors. This incident highlights the importance of conducting a proper mooring analysis. In addition, an improved inspection and maintenance program was instituted.

ROWAN MIDLAND

During a severe storm on April 6, 1981, the *"ROWAN MIDLAND"* suffered three mooring lines failures while the remaining lines remained intact, and prompted the MMS to conduct a detailed review. A laboratory analysis of the failed wire ropes indicated the initial line failed due to fatigue and two lines failed because of sharp increase in tension caused by the failure of the initial line. If the lines were new, an independent mooring analysis showed the lines capable of weathering the storm. Using a realistic breaking strength reflecting on-board conditions for the mooring lines is vital when conducting a proper mooring analysis and is discussed along with other critical aspects of a mooring analysis in Appendix D.

Interim Conclusions:

- Drilling contractors should know the limitations of their mooring systems based on the current guideline set forth in the new API Stationkeeping RP.
- A working maintenance and inspection program is vital in preventing mooring lines failures.
- A realistic representation of the actual breaking strength of a mooring line is essential to a mooring analysis.

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* A chain/wire combination performs very well in deep water, but may not be appropriate in shallow water operations. In shallow water, an all-chain system usually provides the best results.

3.2.2 North Sea

The North Sea environment is far different from that encountered in the Gulf of Mexico. Frequent intense winter storms make MODUs much more likely to see conditions near their design limitations. The wide breadth of the storms means more rigs are subjected to each storm. Table 3.3 is a brief history of semi-submersible performance in the North Sea storms compiled from Noble Denton's Accident Database.

Table 3.3 North Sea Mooring Failures

Event	Number of Units Suffering Mooring Failures	Number Drifting	Number of Units Exposed
November 19, 1973	3	1	
January 3, 1976	3	1	≈ 40
November 24, 1981	6	1	≈ 50
November 6, 1985	4	0	
December 12, 1990	9	0	57
October 18, 1991	5	0	53
January 1, 1992	6	0	49

A great deal of information is available on these failures since the North Sea regulators required reports on all incidents and research has been conducted into the causes.[11,12] What is of great significance is that the number of incidents of a mooring line failure are so high, but in recent years, there has not been one semi-submersible in the North Sea that has broken all lines and drifted. Compare this to the experiences in the Gulf of Mexico during Hurricane Andrew when only three units suffered mooring line failures, but they all moved a significant distance off station. While there are many differences between North Sea operations and those conducted in the Gulf of Mexico, several useful lessons can be learned and are listed below.

Interim Conclusions:

- Operators must take prompt action prior to reaching operating limits to disconnect the riser and take other precautionary actions. Delaying such actions can result in damage to the riser and BOP.

- Manning of rigs during storms allows active measures such as winching and use of thrusters/main propulsion to reduce line tensions. In a number of cases, such action prevented multi-line failures from becoming total failures and a loss of station keeping ability.
- Operational limits must be realistic, clearly defined in the operations manual and adhered to.
- Line failures can occur at tensions far below the catalog break strength of the mooring line.
- Mooring analysis and operational procedures should take into account of the consequence of a line failure. (i.e. one-line damage criteria)
- A number of failures have occurred while using high strength K4 chain. The difficulty in manufacturing high strength chain has lead to greater variability of strength and quality control problems, although the chain manufactures now claim that this is no longer a problem.

3.2.3 Southeast Asia

There is not a great deal of information generally available on incidents in Southeast Asia, but the data in the table listed below demonstrates that other areas sensitive to cyclonic storms, such as typhoons, also experience mooring failures resulting in rigs becoming adrift.

Table 3.4 Southeast Asia Mooring Failures

Event	Area	Number of Units Suffering Mooring Failures	Number Drifting	Number of Units Exposed
August 28, 1986	S.E. Asia	2	2	
April 22, 1989	Australia	3	2	≈ 6
November 3, 1989	S.E. Asia	3	3	

Figure 3.2 Hurricane Betsy '65 Category 4

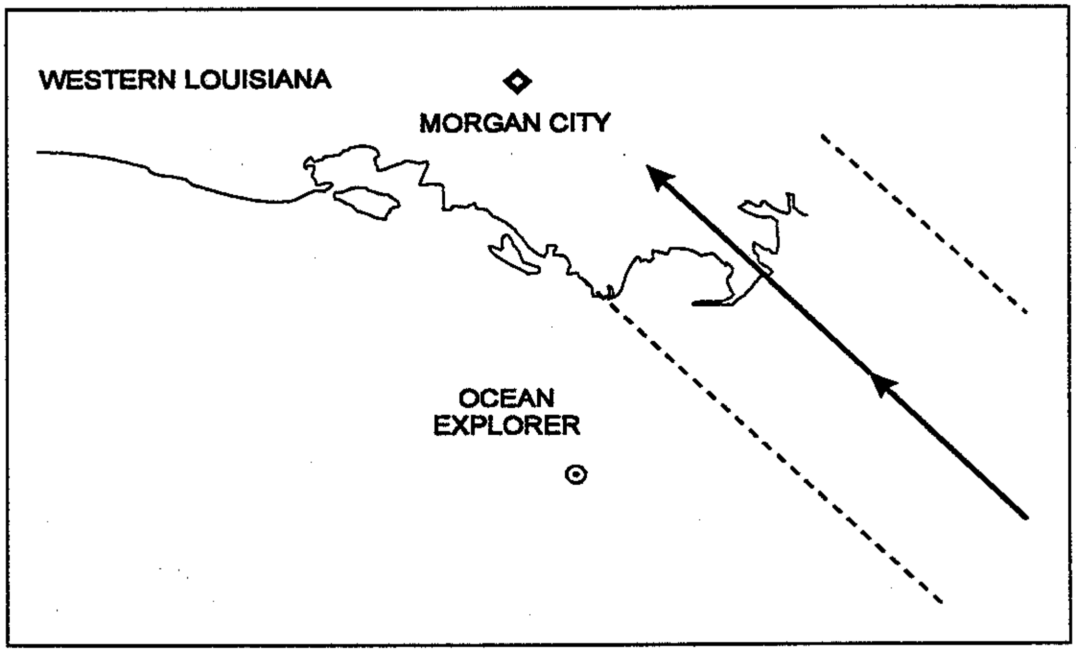


Figure 3.3 Hurricane Camille '69 Category 5

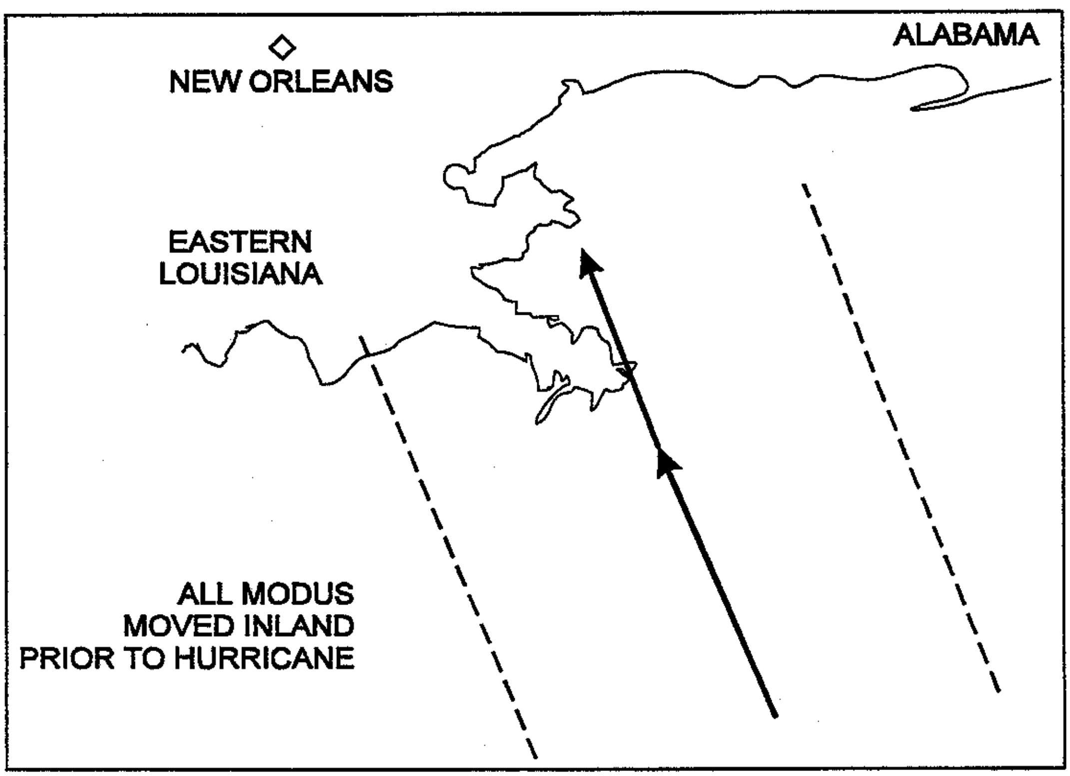


Figure 3.4 Hurricane Edith Category 5

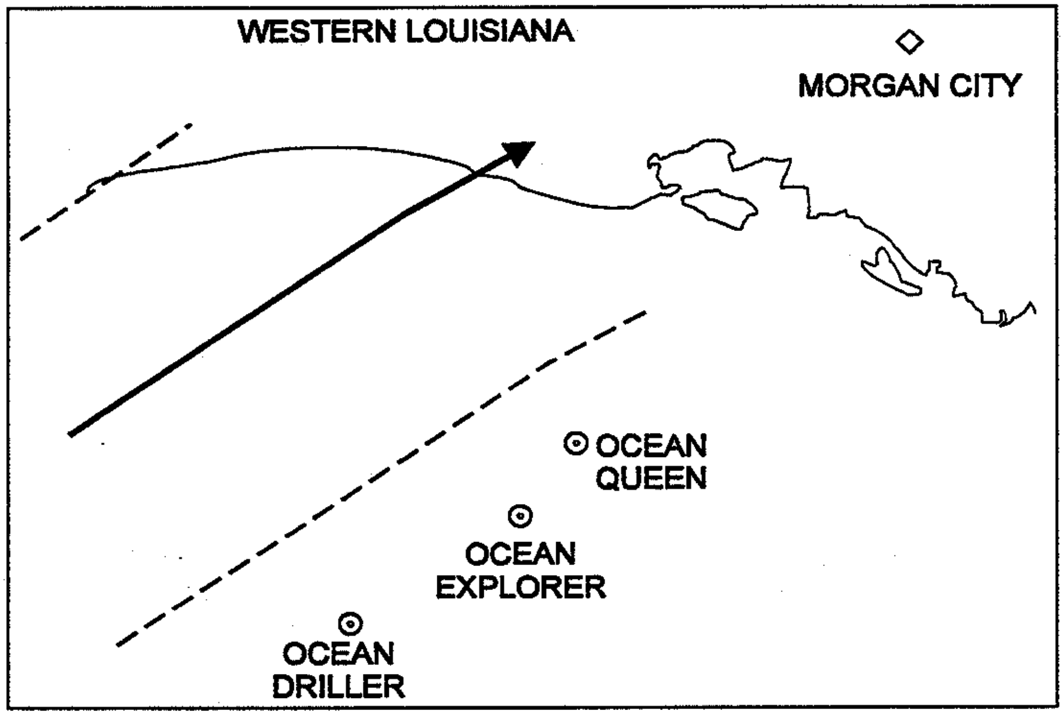


Figure 3.5 Hurricane Carmen '74 Category 4

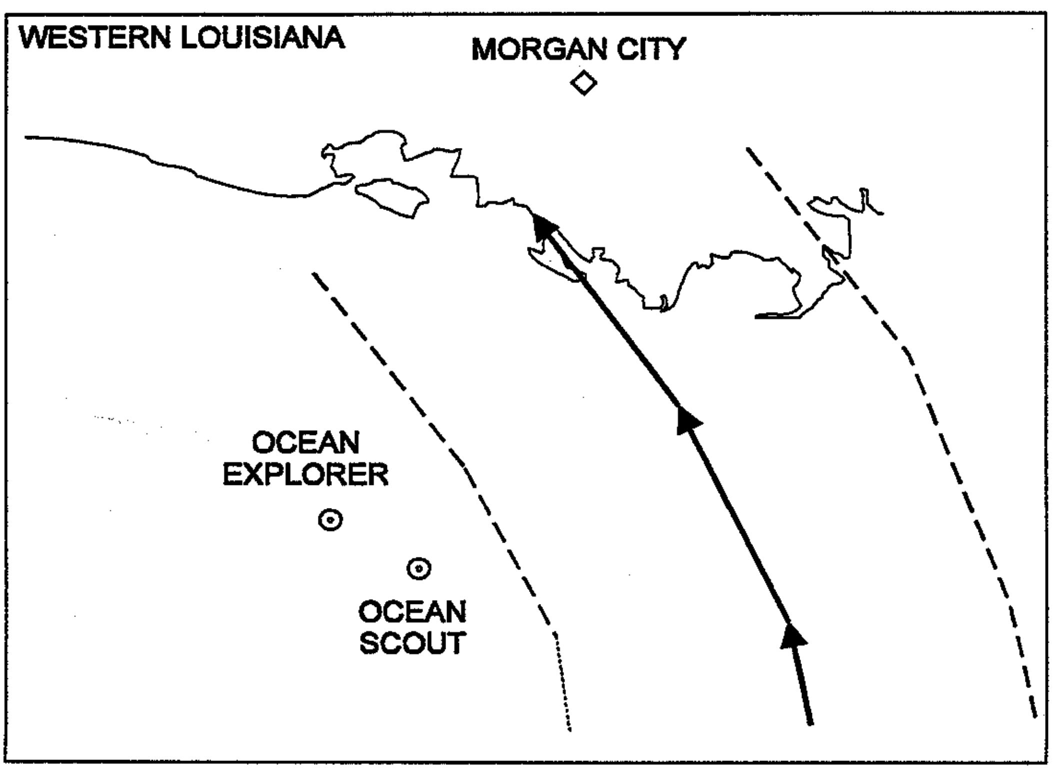


Figure 3.6 Hurricane Eloise '75 Category 3

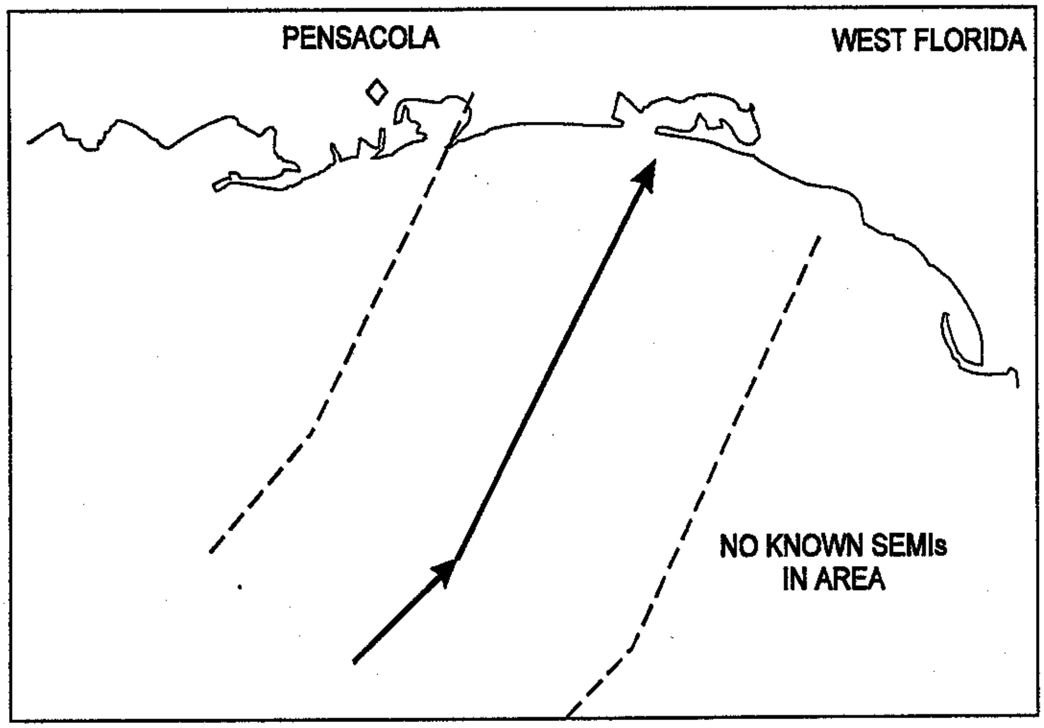


Figure 3.7 Hurricane Frederic '79 Category 4

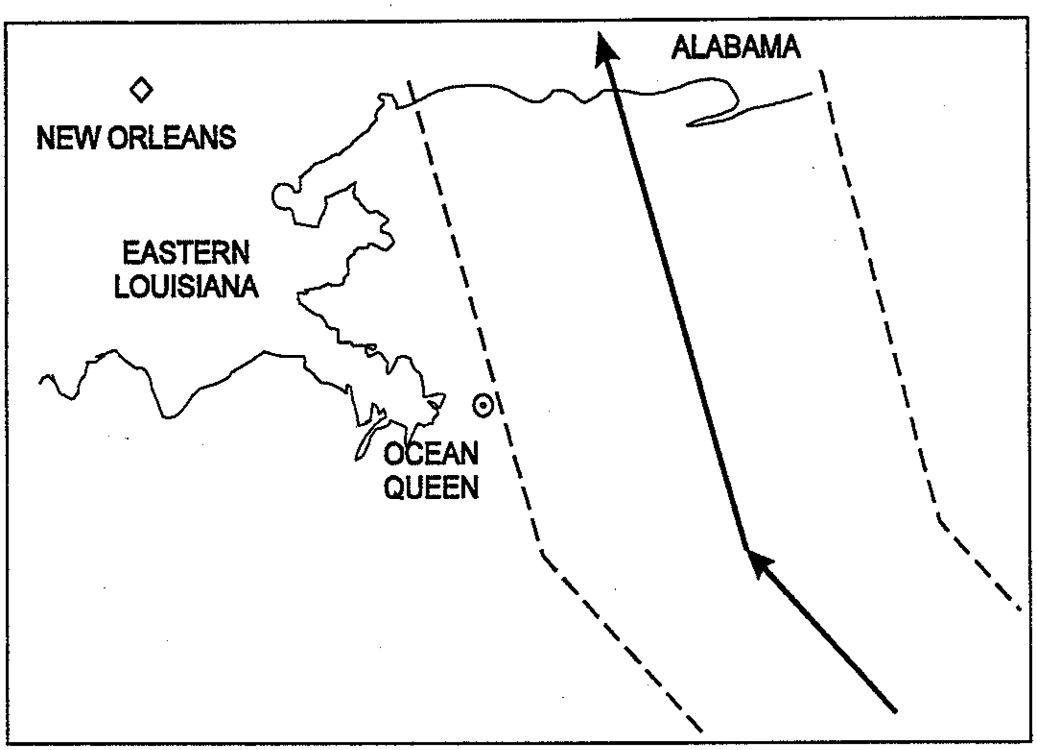


Figure 3.8 Hurricane Allen '80 Category 5

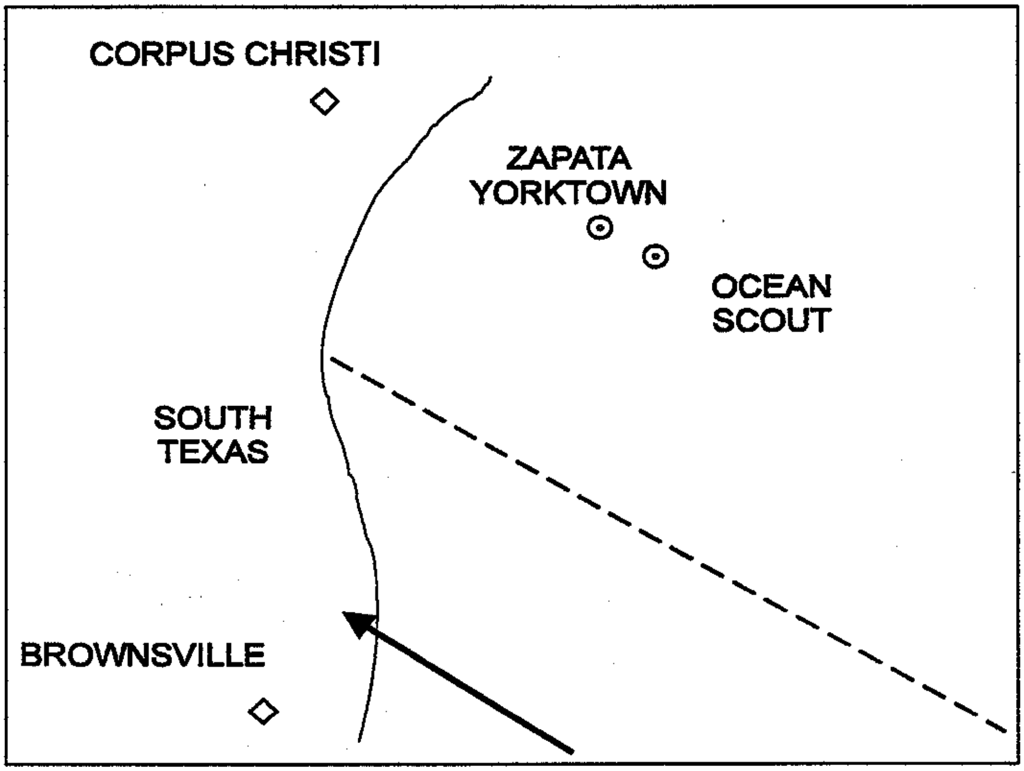


Figure 3.9 Hurricane Alecia ' 83 Category 3

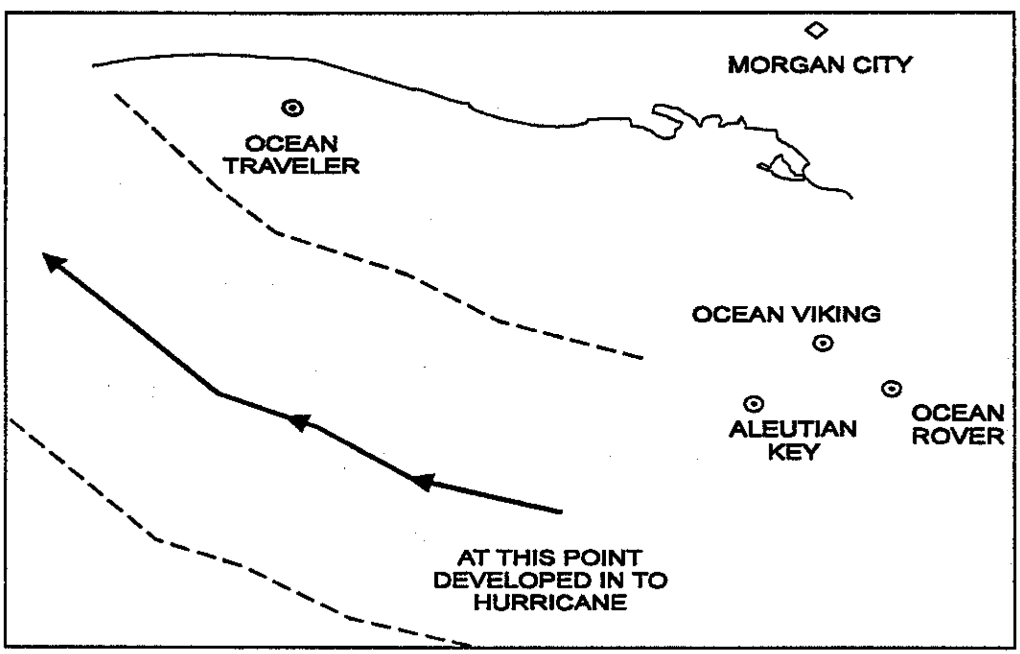


Figure 3.10 Hurricane Elena '85 Category 3

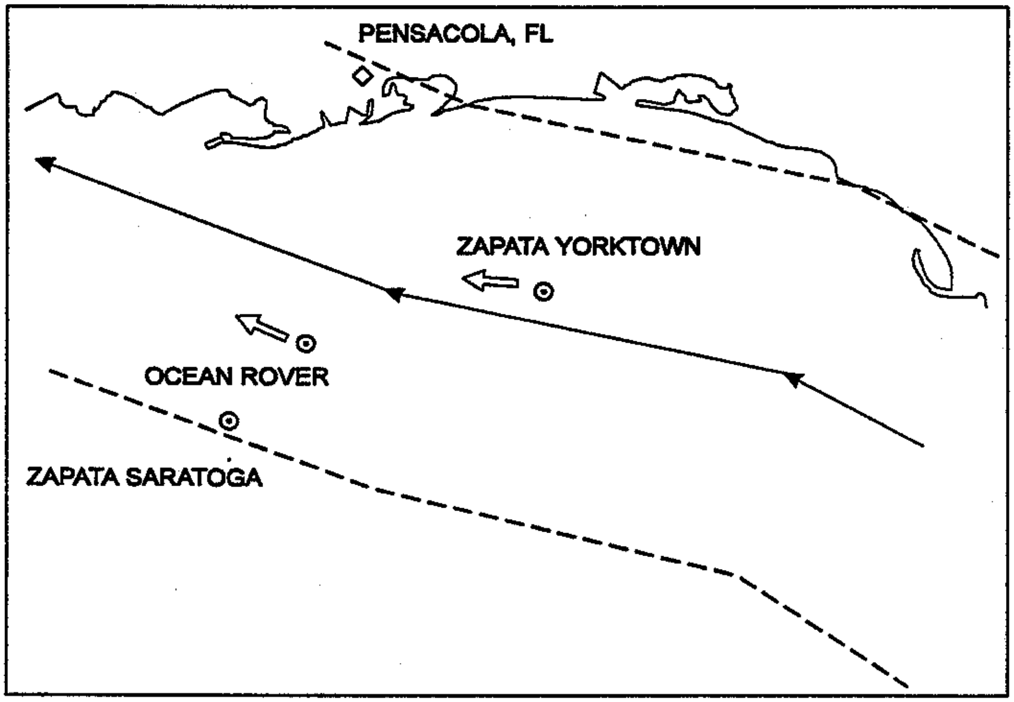
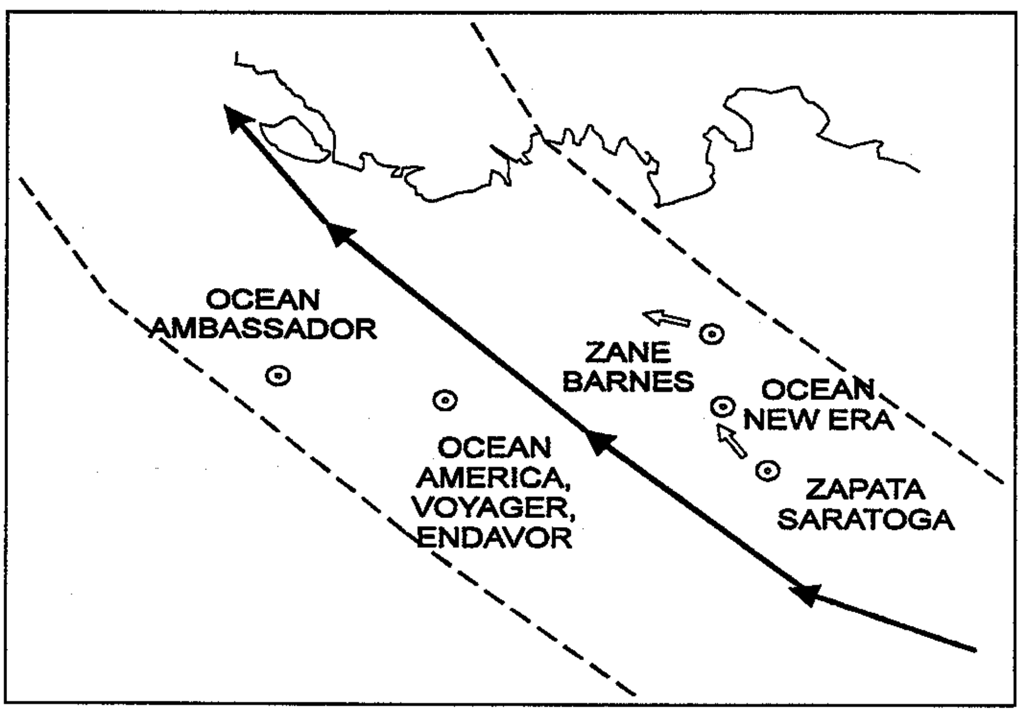


Figure 3.11 Hurricane Andrew '92 Category 4



4. MOORING DESIGN CRITERIA

The new API Station Keeping Recommended Practices (RP) released in its draft form in May 1994 represents the best accumulation of state-of-the-art information for mooring analysis to date. If all semi-submersibles adopted its use in the Gulf of Mexico, it would result in a significant increase in their level of safety. Mooring analyses of the incidents in Hurricane Andrew, as reported in Appendix G, suggests that if the semi-submersibles had been moored in accordance with this new RP, the likelihood of them breaking adrift would have been reduced.

There are still some areas of uncertainty associated with any mooring analysis and Appendix D highlights many of these. The development of a reliability based mooring code would further support a rational assessment of mooring system capabilities and safety, and this section will recommend further research in developing such a procedure.

4.1 API STATIONKEEPING RP

Notable improvements have been made to the new API mooring RP over the existing API 2P last updated in 1987. The new version combines API 2P with the FPS mooring procedures (API FP1) into one edition and allows much of the new technology developed for floating productions systems to be used in a MODU mooring analysis. The draft released in May of 1994 is the initial release for comments from industry, and a yellow draft issue is scheduled to be released in the summer of 1995. A synopsis of a mooring analysis conducted using this procedure is contained in Appendix C, and the following list summarizes many of the changes found in the new RP.

- Significantly increases the design criteria from 99.9% non-exceedance (3 months) to a 5 year return period when operating in isolated areas and to 10 years when operating in close proximity to other structures. In areas sensitive to tropical revolving storms (TRS) such as hurricanes, a risk analysis may be used to determine the design return period, but it should not be less than 1 year.

- Requires use of a one line damage criteria and a transient analysis when operating in close proximity to other structures.

- Allows reduced safety factors for a dynamic analysis of MODU moorings.

- Clarifies the use of low frequency motion and wave drift force tables found in both API 2P and the new RP. These tables were designed for 2nd generation semi-submersibles and use with larger 4th generation semi-submersibles will yield non-conservative results.

- Provides guidelines for thruster assisted moorings for manned operations.
- Improves the anchor holding criteria to incorporate new information on high holding capacity anchors such as the Bruce and Stevpris anchors.

A frequently used analysis procedure outside the United States is the Det Novske Veritas' (DNV) POSMOOR mooring code, and since many differences exist between POSMOOR and the API RP, it is important to highlight these. POSMOOR is extensively used in the North Sea where the required design return periods are longer (Norwegian, 100 year; United Kingdom, 50 year). This has necessitated the use of analysis methods that can produce much lower tensions when compared to an identical rig evaluated under API's RP. For DNV's code, these differences have resulted in a large non-conservative variance between the analytical calculations and the semi-submersible's actual performance, and provides further justification for use of the API Mooring RP. Appendix F provides more details of the differences between the API and DNV analytical procedures.

As with any new draft procedure, there is a certain amount of criticism and need for debate. Three issues that need further examination are:

- <u>Is the 5 year return period for isolated operations sufficient?</u>

  It is understood that the design criteria for semi-submersibles is different than other platforms such as fixed structures, and the reasoning for this is expounded in Appendix D.* The exact criteria, however, should be based on an examination of cost, benefit, and risk considerations, and these subjects are currently the under review by the Mooring Design Code Calibration JIS led by Noble Denton and Associates, Inc.. The review of the *"ZAPATA SARATOGA's"* performance during Hurricane Andrew outlined in Section 2 insinuates that based on the minimal amount of information known, compliance with the 5 year return performance may not have prevented breakaway. While there is a significant difference in the new RP between mooring criteria for isolated operations and for operations adjacent to structures, the

* The arguments put forward include that they will not damage anything if they break loose, that they are only on location for a short time, and that the mooring system is subject to frequent inspection during moves. Most of the arguments are spurious to a greater or lesser extent.

extensive damage caused to structures many miles away by drifting MODUs suggests that the two criteria should be closer in severity for Gulf of Mexico operations.

Possible considerations for improvement in the isolated criteria may be:

- ◊ Require one-line damage analysis for all MODU operations (see following comments), or
- ◊ Increase the design return period for isolated operations to 10 years

Part of the problem stems from the difference in loads between a 5 year return event and a 10 year event. The increase in line loads between a 5 and 10 year storm in the North Sea is approximately 10%, but the difference between 5 and 10 year Gulf of Mexico hurricane induced line loads is approximately 40%.* In the Gulf of Mexico, if the design storm return period is exceeded, then the unit is more likely to suffer a failure than in the North Sea. It also means that the cost of a mooring system in the Gulf is far more sensitive to design return period than it is in the North Sea. This makes it much harder to determine a suitable design premise in the Gulf of Mexico, and put a great responsibility on the relevant code writers and regulatory bodies.

- Should the operational and survival safety factors be the same?

API 2P required a minimum safety factor for line tensions of :

- ◊ Operational - 3.0
- ◊ Survival - 2.0

For the new RP, both operational and survival conditions require a safety factor of 2.0 for a quasi-static analysis. The main limitation for the operational condition is the offset limits and its impact on riser integrity. The reasoning the API RP puts forward is that if the mooring lines satisfy the more severe survival design criteria, there is no need to examine the less severe operating condition for line tensions. Some argue that in the operation condition, the combination of heavy weather and high line pretensions can cause line tensions near their limits. High line pretensions are often used to limit vessel offset and protect the riser. Since with the riser connected, the consequence of a mooring line failure is much more severe than in the survival

* The probability of exceedence is the same in both the North Sea and the Gulf, it is the effect, or consequence, of exceedence that is so different. The problem is even more severe in the South China Sea where the difference in consequences are still greater.

condition; the argument is that the operational safety factor should thereby be higher to assure less chance of failure.

- Should there be a requirement for a damaged line condition?

  The API recommended practices as they are presently configured do not encourage redundancy in a mooring system, and it is redundancy that offers the best protection against mooring system failure. Given that mooring lines, both chain and wire, are susceptible to failure at loads well below their supposed breaking strength, then use of multiple lines, and hence redundancy in mooring systems one should be encouraged. There is nothing to prevent a unit using a four point mooring system, according to the API. This is not advisable since the probability of a single line failure would appear, based on past experience, to be based on additional factors beside line load. In the case of a four point system, one lost line would be equivalent to 25% of the mooring system: given a 12 point system, one line loss is equivalent to just over an 8% loss. The effects of this are particularly important in the operating condition, with riser connected.

4.2 RELIABILITY BASED MOORING PROCEDURE

One of the principal goals of a Joint Industry Study (JIS) currently being lead by Noble Denton and Associates, Inc. is to initiate the development of a unified reliability based, mooring code for adoption by industry, through the International Standards Organization (ISO). To further this end, statistical models and computational methods are currently being developed that are needed for performing the reliability calculations.

The development of a reliability based mooring procedure is an immense undertaking and many analytical tools are yet unavailable to reach this goal. The Noble Denton JIS has identified several areas requiring further research.

These areas of required research in developing a reliability based code are:

- Lack of full scale mooring load test data. This is required to validate assumptions made in modeling various uncertainties inherent to the mooring analytical process. The instrumentation of FPSs currently in use in the Gulf of Mexico presents an excellent opportunity to gather this information. Model test data is not able to support development in the same manner that full scale testing would since there are many inaccuracies associated with modeling a full mooring system especially the second order effects.

- There is a lack of well validated analysis tools to model low-frequency damping and thus motions of a moored vessel. While there has been a great deal of basic research into this area (see Appendix D), there is still a serious lack of adequate analysis tools which can be employed in reliability analysis as well as mooring system design. The problem is exacerbated by a the absence of any full scale data.

5. POSITIONING OF MODUS

A drilling contractor only has the option of selecting a mooring site when a MODU is to be stacked. When a MODU is working, the operator will dictate the location as part of the contract. Because of this, the focus of this section will be in developing criteria to aid a drilling contractor in selecting a stacking location. Two principal areas will be examined:

- Site conditions which effect the mooring system performance (i.e. factors affecting the probability of a mooring line breaking or anchor dragging).
- Factors for a given location that effect the probability of collision with another structure should a failure occur.

Because of the density of platforms in the Gulf, and the random nature of hurricanes, the best efforts to prevent a collision should be on properly securing a rig prior to evacuation. The only sites that result in a significant reduction in the probability of collision, should a failure occur, are in the deep water regions offshore the Central Gulf or the isolated regions off West Florida or West Texas.

5.1 EXISTING SITE SELECTION CRITERIA

A consensus of various drilling contractors surveyed revealed the following criteria in determining a stacking site:

a) An unleased block -- Though there is no legal procedure preventing a rig from stacking in a leased block, it is generally a custom within the industry influenced by, at least perceived, client/operator pressures.

b) The block contains no structures (platform and pipeline) -- For pipelines, this can be difficult to determine since there is no ready reference containing blocks through which pipelines pass. There is a MMS database which contains pipeline start and end locations, but the blocks the pipelines transit must be assumed by the user.

c) Lack of major structures in nearby blocks -- The meaning of "major" could be different to the MMS whose criteria may not reflect "important" platforms that should be avoided.

d) Located within 3 to 4 hour crewboat ride from shore -- This is for logistical reasons and enables quick evacuation of personnel in advent of a hurricane or personnel injury. Any further offshore would necessitate use of helicopters that can be in short supply during critical times, such as during a hurricane. Also without the financial support from an oil company, operations far offshore can be costly and unnecessary when closer locations are possible. Long boat rides affect crews as well, since traveling to and from the rig is done on their own time.

When under contract, the drilling contractor's primary concern is structures and obstructions in the immediate vicinity of the location to be worked. If this region is free of such obstacles, the planning involved in moving on site is relatively simple. Actual practice as to whether the drilling contractor is required to demonstrate to the oil company that the mooring system deployed is capable of withstanding a given weather criteria varies widely.

5.2 SITE CONDITIONS AFFECTING MOORING SYSTEM PERFORMANCE

5.2.1 Soil Conditions and Anchor Type

Soil conditions directly affect the holding capacity of an anchor, and thus the likelihood of an anchor dragging. As various types of anchors perform differently in different soil types, great care should be taken to match the desired performance of an anchor to the anchor type, and its performance in a given soil condition. In general, an anchor is chosen based on its ability to meet a minimum holding capacity under design conditions, but as explained in Appendix D, it can be difficult to accurately determine this value. The tension at which the anchor starts to drag, or the ultimate holding capacity, is not generally well predicted. Because of the characteristics of soil, the minimum holding capacity used in a design calculation and the ultimate capacity can be quite different. The choice of anchor type is normally made during design or construction, often long before even the country of operations is known. A MODU typically has only one type of anchor and is unable to custom fit the anchor type to various soil conditions at each site, though anchors are occasionally changed on specific contracts.

The difference between the minimum and ultimate holding capacity difference is important since a dragging anchor can damage subsea structures in the immediate vicinity, or as in the case of Hurricane Andrew, miles away. A small amount of anchor drag can be beneficial to the overall performance of the mooring system by preventing mooring line breakage. This was illustrated during the examination of the *"OCEAN NEW ERA's"* performance during Hurricane Andrew. A designer must make a choice when selecting a anchor as to whether to oversize the anchor, and therefore, minimize any likelihood of anchor drag, or optimize its size as to be high enough to hold up to design conditions, yet low enough to drag prior to a mooring line breaking, when those conditions are exceeded: a key problem in making this design condition is a lack of documented case histories.

The experience learned from Hurricane Andrew illustrates the difficulty in optimizing the size of an anchor because of the complexities governing soil mechanics and mooring analysis. In Andrew, some rigs did not drag their anchors when it was expected that they would, and others performed as anticipated. In order to examine why this occurred and what impact soil conditions and anchor type had, the following is an accounting of three MODUs located near Hurricane Andrew's path. Details of their anchor types, soil conditions, and estimated holding capacities for these three rigs are listed in Table 5.1 below. Anchor holding capacity curves and tables were originally developed by the US Navy, and were probably designed to give a lower bound on holding capacity. For a mooring system design, a lower bound holding capacity may well be inappropriate.

Table 5.1 Anchor Comparison of Semi-submersibles in Hurricane Andrew

Rig	Anchor Type	Location	Bottom Shear Strength	Design Condition		
				Holding Power (kips)	% of Line CBS	Soil Type
ZANE BARNES	33 kips Bruce F.F. Mark III	Grand Isle Blk 87	0.5 ksf	920	66%	Hard
				720	51%	Soft
OCEAN NEW ERA	22 kip Stevpris Mark III	Grand Isle Blk 103	0.1 ksf	500	56%	Soft
ZAPATA SARATOGA	40 kips Vicinay Offdrill	Miss. Canyon Blk 705	0.05 ksf	380	55%	Soft

ZANE BARNES

The *"ZANE BARNES"* suffered 8 mooring line failures during Hurricane Andrew. Bottom surveys indicate the most loaded lines did not drag. As shown above on Table 4.1, the rated capacity of the anchors using the API tables is far below the break strength. Calculations in Appendix G show anchor loads during Hurricane Andrew exceeding the anchors rated capacity by a factor of 3. When considering why the anchors did not drag prior to the lines breaking, there are many factors to be considered. The primary of these is the variation of the on-site soil conditions with those used to formulate the API tables. The soils in the region in which the *"ZANE BARNES"* was located are unusually stiff for the region [13] and may have bordered on what may be called "hard" soil. It is generally assumed that holding capacity varies linearly with undrained soil shear strength[14] and the specific conditions may have been sufficiently different from those used to generate the API tables for the exact holding capacity to have been large enough to preclude anchor dragging.

The Bruce anchors used on the *"ZANE BARNES"* are modern high holding capacity anchors which exhibit excellent holding capacity in the type of soil conditions found in the Gulf of Mexico. While the values in the API table reflect some of this, these values are considered to be conservative, and the actual performance of the Bruce anchor may be far better. With these factors in mind, it does not seem to unreasonable for the *"ZANE BARNES'"* anchors to have not dragged in the conditions of Hurricane Andrew.

OCEAN NEW ERA

Of the five Ocean rigs near Hurricane Andrew's path, the *"OCEAN NEW ERA"* was closest to the path and suffered the worst weather extremes. While performance data on the Ocean rigs in Andrew is not available, there was a report that one Ocean rig dragged anchors 800 feet. Using hindcast data, a quasi-static mooring analysis for the *"OCEAN NEW ERA"* showed that the maximum line tensions exceeded the catalog break strength by at least 7 percent and the anchor force was 40 percent greater than calculated capacity. If this rig did drag anchors, the anchor drag may have prevented the lines from breaking.

A comparison of this event with the *"ZANE BARNES"* shows the following differences:

- The soil conditions were much softer as compared to the *"ZANE BARNES"*.
- The *"OCEAN NEW ERA"* uses a Stevpris anchor. This is also a high efficiency drag anchor, but it is suspected that they may not have the same conservatism built into their rated capacities that the Bruce anchors have[15].

ZAPATA SARATOGA

A post incident mooring analysis for the *"ZAPATA SARATOGA"* showed similar results to the *"ZANE BARNES"* with the calculated anchor load capacity was exceeded by a factor of 3. Since the *"ZAPATA SARATOGA"* was in comparatively weak soil, and the *"ZAPATA SARATOGA"* uses a lower holding capacity anchor, it would be expected that her anchors should have dragged in conditions such as Hurricane Andrew. A U.S. Coast Guard investigation stated the *"ZAPATA SARATOGA"* broke 7 of 8 mooring lines. Note, if there was any anchor drag, it did not prevent the lines from breaking.

The performance of the *"ZAPATA SARATOGA"* is the most puzzling of the rigs examined during Hurricane Andrew. The following are possible explanations for her lack of anchor drag.

- The material condition of the mooring lines could have been significantly below the catalog break strength or may have failed due to fatigue. If the mooring lines were not maintained properly, the lines may have failed at a value below the ultimate holding capacity of the anchor.
- There may have been anomalies in the on-site soil conditions such as a sand layer which the anchors encountered. This could have significantly increased the capacity of the anchors.
- Additional anchors may have been piggy-backed* with the original anchors, thus adding additional holding capacity.
- The anchors may, in fact, have dragged on-site and subsequently caught rocks or stiff soil during the rig's drifting and caused the lines to break.
- The dynamic loading of the anchors may have been such that the anchor was able to hold far beyond its rated value. Anchors are generally known to dynamically hold beyond the static capacity calculated in field tests, but the magnitude of increase associated with storms is normally in the range of 10 percent.

This incident demonstrates the difficulty in designing an anchor not to drag in order to prevent damage to subsea structures such as those caused during Hurricane Andrew. If the 7 most leeward lines were the ones to fail first, the rig, as might have happened in this

* Older low efficiency anchors often require in soft soils an additional anchor to be laid in line with the original anchor to increase the total holding capacity to the meet the anchor proof load. This term is called piggy backing anchors.

case, would have moved to a new equilibrium position down wind of the least loaded line. The anchor, which was originally leeward, would become inverted and pulled in the opposite direction. This can cause an anchor to unseat and become unstable leading to anchor drag. As a result, if a designer oversizes the anchors so as not to allow drag, anchors may be unseated due to a shift in equilibrium, and still result in one or more anchors dragging.

Again, this case demonstrates the importance of knowing the specifics when attempting to identify causes of failure and indicates investigations must be made in order to allow any real lessons to be learned.

5.2.2 Water Depth

The water depth in which a semi-submersible is stacked can have a critical influence on its survival prospects, and for most units there is an optimal water depth. Figures 4.1 and 4.2 plot mooring system capacity against water depth for two typical MODUs. The peak of the curves is the optimal water depth for the given mooring system, and as shown in Figures 4.1 and 4.2, a water depth between 1000 and 2000 feet generates the sturdiest system.

The mooring system performance curves reflect a series of quasi-static mooring analyses for various water depths using the maximum line length possible. Limitations on line length were as follows; for chain/wire systems, maximum possible while keeping the wire in suspension under pretension loads, and for all-chain systems, length was limited by winch capacity in shallow water and maintaining a minimum reserve in deeper water.

These curves show that as a rig is moved into shallow water, the capacity of the mooring system decreases. This reflects a increase in mooring system stiffness as water depth decreases, and for a stiffer system, a given vessel offset will produce larger tensions.

The choice of an optimal water depth can be in conflict with the requirement that a stacked vessel be close to shore for logistical reasons. There are very few locations in the Gulf of Mexico in the range of 1000 to 2000 feet water depth within a 3 to 4 hour boat ride. Because of these conflicting requirements, the best solution, when stacking a rig, may be to ballast the rig on the bottom as close to shore as possible. This avoids the decrease in mooring system capacity when stacking in shallow water and maintains the rig close to shore. Several semi-submersibles, however, have thruster systems that would preclude ballasting onto the bottom.

Interim Conclusions:

- The optimal water depth to moor semi-submersibles is dependent of the specific rig but normally ranges between 1000 to 2000 feet.
- Shallow water, in addition to deep water, must be examined when determining the operating limits of a moored semi-submersible.
- It is important to consider the actual on-site soil conditions when choosing an anchor type or calculating anchor holding capacity.
- Anchor holding capacity is difficult to predict accurately. Not only are the site specific soil conditions rarely known with sufficient accuracy, but also the analytical model available for predicting holding capacity in various soil conditions is not yet adequately developed.
- Oversizing drag anchors does not preclude an anchor from dragging.
- If anchor drag is to be relied on to limit mooring line loads, further research is required to develop techniques to predict the ultimate holding capacity of anchors.
- Anchor drag incidents should be investigated, as should all mooring line failures incidents, so that present analytical techniques can be calibrated, and improvements can be made to current practices.

5.3 FACTORS EFFECTING LIKELIHOOD OF COLLISION

In order to find the influence of a given location on the probability of collision, this study investigated the following factors: the likelihood of a given location experiencing a hurricane of sufficient strength to break the moorings; should a failure occur, the likelihood of a MODU colliding with a platform.

This section utilizes a computer model developed in cooperation with University of California at Berkeley Department of Naval Architecture and Offshore Engineering to predict a MODUs annual probability of catastrophic mooring failure and subsequent collision with a platform. Using this program, various MODU locations were examined to determine the influence on the overall probability of collision, as explained below. Details of the hurricane model and MODU path predictor used in this simulation are contained in the attached report, *Development and Verification of a Computer Simulation Model for Evaluation of Sitting Strategies for Mobile Drilling Units in Hurricanes*. The program uses a relatively simple mooring model, but the strength of the mooring system can be modified to account for some of the non-rigorous mooring load calculation techniques. The accuracy of the model was calibrated using data from the rigs that moved during Hurricane Andrew. The predicted paths of the *"ZANE BARNES"* and *"ZAPATA SARATOGA"* yielded good correlation with actual results.

An attempt was made to model the expected path of the *"MARLIN 3"*, after its legs broke during Andrew (the *"MARLIN 3"* is a jack-up). The results showed that the jack-up failed while in the west half of the hurricane, so the winds tended to push the unit offshore. The rig then stayed away from the shore until after the hurricane had passed, and the winds died down. It was only then that the prevailing southeasterly winds pushed the unit towards the shore. It is for this reason that virtually all MODUs that break loose during a hurricane will, relatively, quickly end up moving towards the beach. Consequently, it is imperative that a crew get out to a MODU as quickly as possible after a hurricane in order to ascertain if it is still intact and is a potential threat to other structures.

5.3.1 Hurricane Path

This study found little correlation between the site selected and a decreased probability of encountering a hurricane, except for locations on the west coast of Texas. The random nature of the hurricane path is the main factor contributing to this. In the computer model, the hurricane's origin generated in each simulation is based on study by Ward[16] where the Gulf is divided into four regions, each with a given annual hurricane rate of occurrence. Within each region, the probability of the hurricane passing through any given location is uniformly distributed and thus equal. Therefore the only beneficial location for a MODU to help avoid a hurricane would be in a region with a lower hurricane occurrence rate. According to this model, moving a MODU from south of Louisiana, to off Texas, would result in a 20 percent reduction in the likelihood of a MODU encountering a hurricane. All other regions yielded approximately the same probability of encountering a hurricane.

5.3.2 Platform Proximity

A survey of various locations did not find anywhere where the probability of a collision with a platform was significantly reduced. The high density of platforms within the Gulf ensured that, should a failure occur, a collision with a platform was likely. There are non-leased blocks with no major structures in the surrounding blocks, but a drifting MODU can easily drift 20 to 40 miles beyond the clear region and into a densely populated block. In order to reduce the probability of a collision, a MODU would have to be moored in a very sparsely populated region such as off the West Florida coast, offshore West Texas or in deep water regions far offshore in the Central Gulf.

To determine how far offshore a MODU in the Central Gulf region would have to move in order to achieve a significant reduction in the probability of collision, a series of simulations was conducted varying the distance from the MODU to the closest platform. The results of these simulations are shown in Figure 4.3. The conclusion drawn from these results is that a MODU would have to be moored at least 40 miles south of the nearest platform to result in a minimal probability of collision, given the assumption that a mooring failure occurs. Assuming the majority of platforms are located within 75 miles of shore, this would require a MODU to be moored approximately 115 miles offshore.

If future risk analyses for sitting MODUs are to be conducted, it is recommended that platforms be designated which are high value or that pose significant environmental threat. This will allow future risk studies to examine the probability of collision with these "important" platforms and eliminate the problem posed by the high density of platforms where the difference between the number of mooring failures and the number of collisions is small.

Interim Conclusions:

- The owners of MODUs should endeavor to get out to their units as quickly as possible after the passage of a hurricane in order to prevent any that have broken adrift from drifting further, under the influence of the prevailing winds, thereby threatening other structures.
- Given the assumption a mooring failure will occur, safe stacking locations are minimal due to the density of platforms in the Gulf. In general, a unit would have to be moored:

  1) Approximately 115 miles offshore in the Central Gulf region.

  2) In isolated areas such as off West Florida or West Texas.

- Particularly high risk or high value platforms should be specifically designated, along with platforms that would pose significant environmental danger if damaged. This would enable future risk studies that examine specific mooring locations with greater precision.

- A database of blocks which pipelines transit should be created as an aid to drilling contractors or operators in determining locations to moor MODUs.

Figure 5.1 Mooring System Performance For Semi-Submersible "A" to 5 yr. Storm Criteria

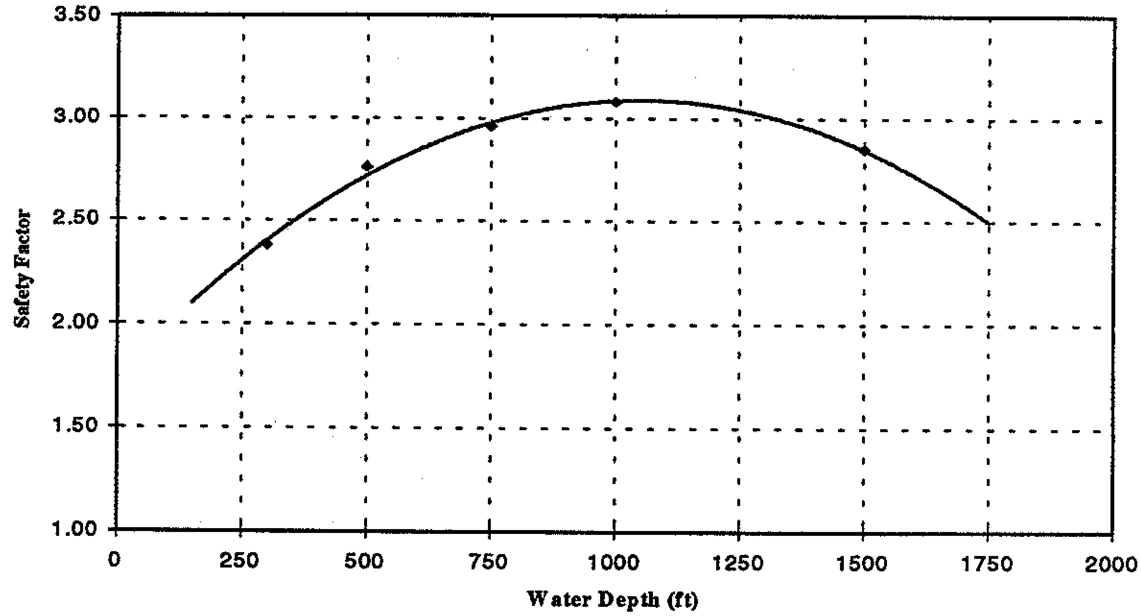


Figure 5.2 Mooring System Performance For Semi-Submersible "B" to 5 yr. Storm Criteria

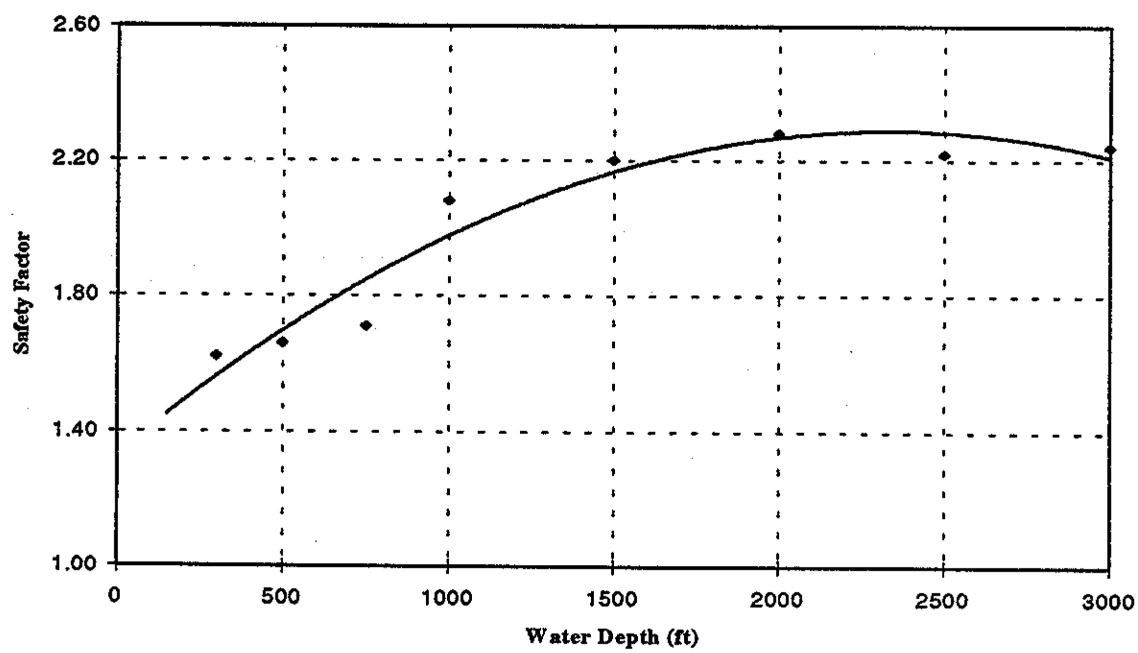
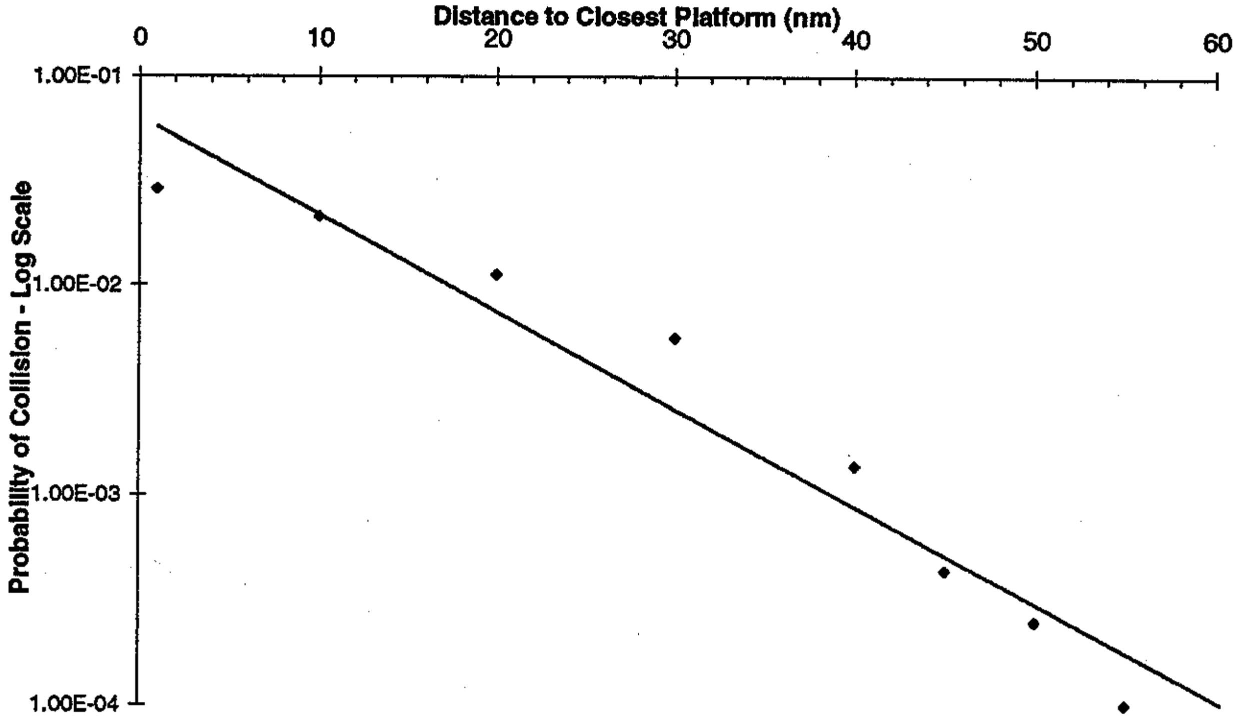


Figure 5.3 MODU's Annual Probability of Collision with a Platform



6. JACK-UPS IN HURRICANES

Historically, jack-ups have performed well in hurricanes, although during Hurricane Andrew, which is the worst hurricane from the offshore industry's standpoint in recent history, a total of 9 jack-ups received some degree of damage. Most of the damage was minor, but the *"MARLIN 3"*, a Bethlehem 265 mat rig, suffered leg collapse, and the hull drifted some 50 miles before running aground. The damage from Hurricane Andrew to jack-ups could have been worse since the majority of jack-up were in shallow water at the time, or were sufficiently far from the path of the hurricane to escape damage. Because of this, it is difficult to use Hurricane Andrew to calibrate current operating practices of jack-ups.

The normal survival criteria that is used for jack-ups around the world is that they should be capable of surviving a 50 year return period storm, however, in the Gulf of Mexico the commonly used design condition is the 10 year storm. There are different interpretations put on the definition of "survival", some saying that the unit should suffer no damage in the survival storm, while others just say that the unit should not suffer catastrophic collapse, but the acceptance of the 50 year criterion outside tropical revolving storm (TRS) areas is close to universal. The reason that TRS areas are treated differently is that it is generally accepted that a jack-up can be evacuated, leading to no loss of life, and that the evacuation condition of the jack-up can be optimized to enhance its survival capabilities.* Historical data would suggest that the use of a 10 year storm is reasonable, in that there have not been that many jack-up failures in the Gulf of Mexico hurricanes. This may be because, as in Hurricane Andrew, not many have been hit when operating close to their limits. Although a jack-up would be expected to be exposed to its "design" environmental conditions of a 10 year storm once, on average, every 10 years, it is very unlikely to be exposed to both its design condition and be operating in a water depth close to the limits.

Jack-ups can be very sensitive to changes in water depth since the overturning moment on the unit will tend to linearly worsen with increasing water depth. While semi-submersibles can be very sensitive to water depth, they are not generally as sensitive as

* Most of the time rigs are abandoned prior to the passage of a hurricane, however, hurricane Juan is a notable recent exception in which many rigs were fully manned. It was during hurricane Juan that the *"PENROD 61"* collapsed and drifted into the sister rig *"PENROD 60"*, later running aground. Fortunately all of the crew managed to evacuate the unit, but one died prior to being rescued.

jack-ups. Figure 6.1 is a plot of the overturning safety factor for a common jack-up against the mooring line failure safety factor for a semi-submersible. The scales have been modified to allow both to fit on the same axes, so absolute safety factors have no meaning: the importance is the slope of the line. It can be seen that while the safety factor for the semi-submersible has a minimum in both deep and shallow water conditions, the jack-up consistently gets worse as the water depth increases.

Another factor that has a significant effect on jack-ups is the direction of storm approach. Certain types of unit are very susceptible to taking on additional penetration when oriented such that they have one leeward leg with respect to the storm (c.f. *"PENROD 61")*, but have very high survival capabilities from other storm directions. Site specific analysis generally considers a disadvantageous orientation. Thus, there is additional safety factors from orientation in preventing collapse when encountering the design storm while operating in deep water.

A number of jack-ups are operated outside what would normally be considered their reasonably acceptable hurricane season operating limits. As seen from the accidents on *"PENROD 61"* and *"MARLIN 3"*, jack-ups can go adrift and become a threat to the platforms. Currently there is neither any regulatory limitations for jack-ups nor any requirement for owners to control their operating limits.

6.1 EFFECTS OF EVACUATION CONDITION ON JACK-UP'S SURVIVABILITY

In maximizing a jack-up's survivability in a hurricane, it is important to know the most likely failure mechanism. For example, for one particular class of jack-up, the most likely failure mechanism is additional leeward leg penetration due to a lack of preload. In order to maximize its probability of surviving a storm, consumables should be discharged so that the variable load is minimized when the jack-up is evacuated The effectiveness of the preload capability, while limited, is at least maximized. (When preload is taken onboard, any shortfall in variable load is made up in additional preload water. If the unit has less than full variable load onboard during a storm, therefore, the effective preload is increased.) The same type of argument applies if leg strength or jack holding capacity is limiting; it is advantageous to minimize the weight of the unit when it is abandoned.

If, the limiting factor is overturning or windward leg sliding, then it is advantageous to maximize the weight of the unit on evacuation. Care, of course, needs to be taken to ensure that the critical mode is not changed from overturning to preload by having too much variable load onboard. It is also worth noting that in most areas of the Gulf of Mexico, the soils are so soft that it is very unlikely that a unit would actually overturn. Given that it is not unusual to take over 24 hours to pull the legs out of the seabed when moving a rig, it is unlikely that they will pull out in a few minutes of maximum load.

Most operating manuals specify that the unit should be left with the hull center of gravity at the centroid of the legs. This is often not a feasible proposition for the abandoning crew if the rig has been drilling an exploratory well, then it may be that the only support for the conductor is provided by the drill floor. If the cantilever is skidded in to move the center of gravity forward, then the well is left un-supported. Given hurricane conditions, it is likely that the conductor will fall over, and could seriously damage the jack-up's legs. It can also be important, when analyzing jack-ups, to include the wave forces on such appendages as the conductor if it is going to remain attached.

Rig heading, with respect to the storm, can affect a jack-up's survivability, by minimizing the loads in the critical directions. Generally it is not possible to orientate a jack-up with respect to hurricanes, but that is not always the case when they are near to shore. It is always worth considering if rig heading can help survivability, even if it can not always be made to count.

Air gap can be an important parameter to optimize, on evacuation. If the air gap is too low, the consequences are likely to be disastrous as any wave impact on the hull would vastly increase the loads, probably, to more than the design condition. Increasing the air gap should not be a problem for most jack-ups, unless they are working in water depths near their capability, when the leg length maybe limiting. Too great an air gap can also be a problem. In a hurricane, wind loads may generate up to approximately half the environmental load. The higher the hull is, the greater the wind load (because of the effects of velocity profiles) and the greater the wind overturning moment. A jack-up in exploratory mode will not have too high an air gap as it makes the loading of equipment and supplies loading difficult, but if it is working over an existing structure, it may be at a very high air gap. In many cases, it would not be possible for the rig to skid in and jack down to a lower air gap, but that is not always the case. If the jack-up's survivability depends on it, it may be worth considering.

The variable load optimization which can take place to either increase the overturning resistance or decrease the leg stresses, is very rig and sometimes site specific. Incorrect instructions with regard to this optimization have occurred in the past and have left jack-ups in higher risk of peril than before the optimization began.

6.2 CONSEQUENCES OF JACK-UP FAILURE

It is generally assumed that the consequences of a jack up failure, if evacuated during a hurricane, would be tolerable. The crew will have set a storm choke, so the probability of an oil spill is minimal, and all the crew are off, so loss of life is avoided. Unlike a semi-submersible, a jack-up is fixed to the seabed, so will not float away and knock over other structures. Although most of the points concerning jack-up collapse consequence are correct, the last is not. Most of the jack-ups that have collapsed in recent hurricanes have floated off, and in many cases it has been for some considerable distance. The "*PENROD 61*", when it collapsed in hurricane Juan, drifted north and ran into the manned sister vessel the "*PENROD 60*". It is fortunate that it did not cause the "*PENROD 60*" to collapse, which could have led to a heavy loss of life. Having collided with the "*PENROD 60*" the unit then drifted a considerable distance before sinking in shallow water. The "*DIXILYN FIELD 81*", which collapsed in hurricane Allen (in 1980), drifted approximately 10 miles before capsizing and sinking. As stated above, the "*MARLIN 3*" drifted after it collapsed in hurricane Andrew, and there is some strong evidence that it hit some other structure before running aground.

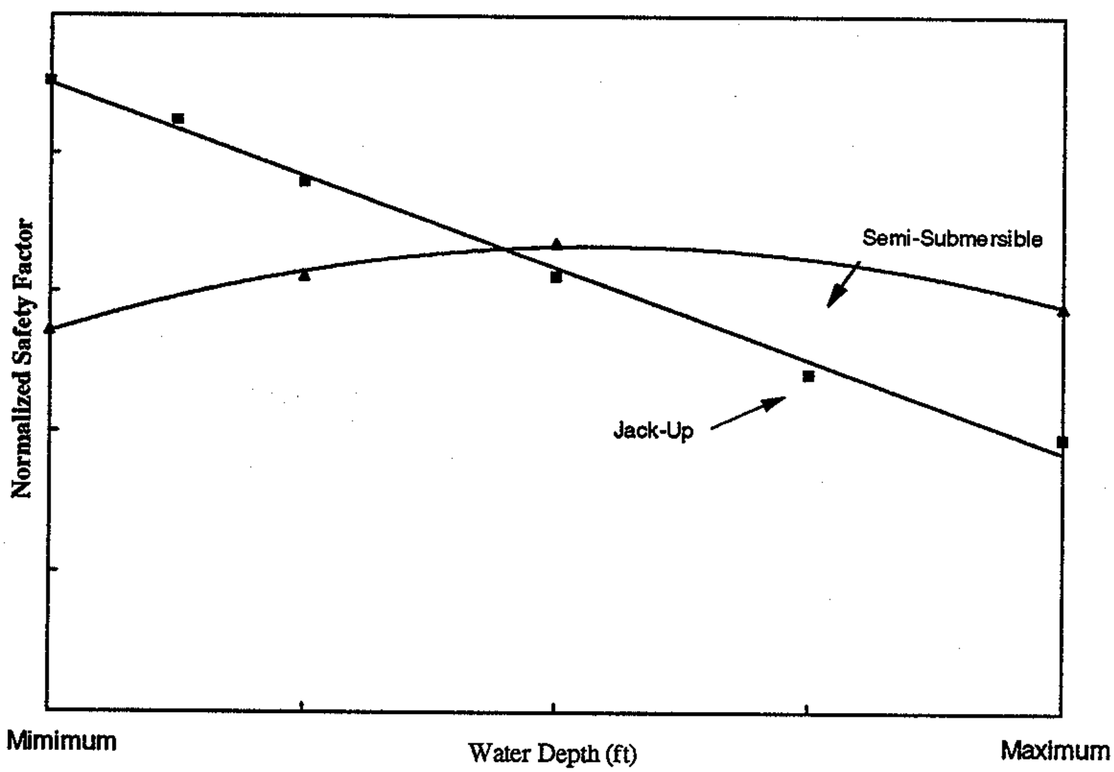
Although there are no documented cases of occurrence, a jack-up that has collapsed could cause serious pipeline damage while drifting. In most of the cases, there has still been some broken leg extending below the hull which could drag the seabed for some considerable distance, with the commensurate danger of pipeline damage.

Interim Conclusions:

- There should be some unified and consistent way of ensuring that jack-ups do not operate outside their areas of capability particularly when operating over or in close proximity to production platforms.
- Drilling contractors should be given the facilities within the operating manuals to ensure that they can maximize their jack-ups' survival capabilities by being informed of the critical failure mechanisms, and the optimum condition in which to leave the unit.

- Jack-ups should not skid the cantilever in if it will entail leaving an unsupported conductor that could fall into the legs but the water depth capability should be evaluated with due regard to this limitation.

Figure 6.1 Comparison of Relative Performance for a Semi-Submersible and Jack-Up



7. SUBMERSIBLES

In Hurricane Flossie (1956), when the majority of mobile rigs were submersibles, a significant number of them operating in the Gulf of Mexico moved a limited distance and damaged the wells that they were drilling, but rarely have these units moved sufficient distance to be a threat to structures other than those by which they were operating. This record was changed during hurricane Andrew in which two Portal rigs moved approximately 5 miles each. There was no investigation as to why these units moved, what their bottom pressures were when abandoned, or if they were properly secured prior to the passage of Andrew. Based on past experience with hurricanes and submersibles, it appears that a bottom pressure of 250 pounds per square foot will normally be sufficient to resist sliding, but it is interesting to note that during Flossie there were units that slid small distances, even though they had bottom pressures in excess of 250 pounds per square foot. Indeed, it is suggested[17] that all submersibles should be piled to assure no movement during the passage of a hurricane. Reference 17 is probably being a little overly conservative, and more recent experience would suggest that proper ballasting is all that is required to prevent significant movement.

There are certain mud slide areas within the Gulf of Mexico where ballasting to any specified bottom pressure will not prevent movement in a hurricane, as the movement is caused by the gross flow of the underlying soils. It was this that caused the failure of the "*HARVEY WARD*", a mat supported jack-up, in hurricane Allen in 1980. While a unit that moves due to a mudslide may damage a pipeline, it is very unlikely that it would damage a pipeline that would not be damaged by the slide.

Interim Conclusions:

- All submersibles, and semi-submersibles that have been ballasted onto the seabed for the passage of a hurricane, should be ballasted to at least 250 pounds per square foot.
- Submersibles or mat supported jack-ups that operate in the mudslide areas around the Mississippi delta when conditions are likely to be conducive to mudslide occurrence, should be evaluated at the location by a qualified expert in local mudslides.

8. OTHER MOORED AND FLOATING EQUIPMENT

There are a number of other moored and floating vessels out in the Gulf of Mexico during hurricanes. Most offshore equipment will try to gain the shelter of a port during a hurricane, but that is not always possible due, most commonly, to a shortage of tugs. Some example of such equipment would include:

- Derrick barges
- Drilling Tenders
- Semi-submersible Crane Vessels
- Temporary Well Flow Test Barges
- Transportation Barges (e.g. with jackets or deck structures)

Sometimes the equipment is designed to survive severe weather conditions, such as the semi-submersible crane vessels, but most of the rest are unlikely to have sufficiently strong moorings. Occasionally vessels can get caught out when least expecting it. There was a jacket on a barge that was towed out into the Gulf for installation by a derrick barge but, the crane broke down, thereby delaying the lift to such an extent that both barges were caught off guard by a locally generated hurricane. Fortunately, nothing was damaged, but given the wind area of a jacket on a barge, the owners were extremely lucky.

9. CONCLUSIONS AND RECOMMENDATIONS

There are a number of specific conclusions that can be drawn from this study. Most of these are itemized as "Interim Conclusions" in the body of the text, and the more important ones are reiterated below, with some expansion, where needed.

- Historically, semi-submersibles lack of exposure to hurricanes is the principal factor contributing to the small number of mooring failures in the Gulf of Mexico. With a greater exposure, there would almost certainly be a significant increase in the number of vessels that break loose, and a consequential increase in the number of structures damaged by the drifting semi-submersibles.
- The current API 2P 99.9% non-exceedence design criteria for MODU moorings is insufficient to prevent mooring failures in hurricane. The new proposed API RP will significantly increase the probability of semi-submersibles staying on location.
- It is difficult to determine whether a potential mooring location is free of subsea structures since there is no database of pipelines that indicates where the lines actually run. All that is available is a list of start and end points.
- Given the assumption a mooring failure will occur, safe stacking locations are minimal due to the density of platforms in the Gulf of Mexico. In general, a semi-submersible would have to be moored:
    1) Approximately 115 miles offshore in the Central Gulf region.
    2) In isolated areas such as off West Florida or West Texas.
- The optimal water depth for mooring semi-submersibles is dependent on specific design but normally ranges between 1000 to 2000 feet. If the water is too shallow, the wave and low frequency motions cause high tensions, and if the water depth is too deep, the additional weight of mooring line deployed, and the mooring line dynamics will cause high tensions. Locations with this water depth and in close proximity to supply bases, however, are minimal.
- The best place to stack semi-submersibles, when they are not working, is ballasted onto the bottom close to shore (with a bottom bearing pressure of at least 250 psf). This minimizes the chance of them moving in a storm, and allows the drilling

contractor easy access to them. This is not always a viable option; for example, if the vessel has protruding thrusters.

- It is not practical to move MODUs inland during the onset of a hurricane because the semi-submersibles tend to be working further offshore in deeper water and it would take too long to pull the legs of jack-ups free from the seabed. Even if it were feasible to move the MODUs, it would not necessarily be advantageous, as they could break loose in the high wind speeds and storm surges in port or during transit to port.

- Manning of rigs during storms allows active measures such as winching and use of thrusters/main propulsion to reduce line tensions. In a number of cases, such actions have prevented multi-line failures from becoming total failures and a loss of station keeping ability. While leaving units manned may not be a viable option in the Gulf of Mexico during the passage of a hurricane, the advantages of manning should not be overlooked.

- A small amount of anchor drag can be beneficial in preventing mooring line breakage by allowing some redistribution of line loads, but it can be difficult to accurately predict when slippage will occur, especially given the variety of soil conditions that there are in the Gulf of Mexico. In some cases, the holding capacity of the anchors can be much more than would normally be expected using standard published data: The assumption of slippage, in the analysis, can then become dangerously un-conservative. Conversely, if there is too much slippage, then the unit can drift a significant distance and potentially damage other structures and/or pipelines.

- Mooring line failures can occur at tensions far below the catalog break strength of the mooring line. In chain, this may be due to either manufacturing defects or handling damage; in wire it is normally due to age and handling. It is important to note that CBS for chain is the Catalog Break Strength, and NOT the Certified Break Strength. All chain is tested to a proof load of 70% CBS, but only 1% is tested to CBS, and some failures are allowed without rejecting the chain.

- Semi-submersibles can, and have, broken loose in winter storms, so hurricanes are not the only threat. The concern about winter storms is increased because there is a chance that the rig crew may not disconnect their riser quickly enough, thereby running the risk of pulling the BOP off the seabed, leaving an open hole and causing a major blowout. Indeed, the ""*OCEAN TRAVELER*"" did pull the BOP off the seabed in the 1983 winter storm in the Gulf, and the same thing has happened at least twice in the North Sea, although fortunately none of these incidents has led to a blowout.

- There is a lack of well-validated analysis tools to model low-frequency damping of a moored vessel. While there has been a great deal of basic research into this area (see Appendix D), there is still a serious lack of adequate analysis tools that can be employed in reliability analysis as well as mooring system design. The problem is exacerbated by an absence of any full scale data. There is some scale data, but model basin effects could seriously affect the accuracy of this.
- A working maintenance and inspection program is vital in preventing mooring lines failures.
- The potential for damaging remote structures is not confined to semi-submersibles: jack-ups have drifted many miles after collapsing, and for example in the case of the "*PENROD 61*" during Hurricane Juan, it damaged another structure and put lives at risk.

RECOMMENDATIONS

- All mooring incidents should be not only reported to the USCG, but they should also be fully investigated. It is only by investigating failures that the reliability of mooring systems can be understood, and consequently improved. The investigation should cover anchor dragging incidents as well as mooring line failures even those without a storm incident. At present, severe storm incidents are reported, but not investigated in sufficient detail by the USCG. An extension of this is that a better historical database needs to be maintained of past MODU incidents.
- Detailed investigations should be conducted of all units exposed to hurricanes in order to learn more on preventing future damage. A recommended format for these investigations is contained in Appendix H.
- The use of the new API Stationkeeping RP provides a better security against semi-submersibles mooring failures. Regulatory authorities should continue to support this development.. Considering the minimal information available from Hurricane Andrew, the current 5 year criteria, however, may be insufficient to preclude mooring failures in another hurricane the size of Hurricane Andrew.
- Drilling contractors should know the limitations of their mooring systems, based on the current guideline set forth in the new API Stationkeeping RP. A realistic

representation of the unit's operating and survival capability should be included in the operating manual.

- Mooring analysis and operational procedures should take into account of the consequence of a line failure, regardless of whether the unit is operating close to a fixed structure.
- When possible, semi-submersibles should be stacked ballasted onto the seabed with a bearing pressure of at least 250 psf. Where this is not possible, the semi-submersible should be stacked in sufficient water depth to minimize the chance of mooring failure.
- After the passage of a hurricane, it is extremely important to go out to the various drilling units as quickly as possible. If a unit has broken adrift, there is still a possibility that it will not have collided with anything, or run aground: it may, for example, have been on the backside of the hurricane, and not drifted towards the shore. Without a rapid response, the southeasterly prevailing winds in the Gulf will tend to push any free floating object towards the shore and other platforms.
- A realistic representation of the actual breaking strength of a mooring line is essential to a mooring analysis. At present there is little consistent data on chain breaking strength. Research should be undertaken, or the chain manufacturers be encouraged to supply, chain break load data.
- If anchor drag is assumed in the mooring analysis procedure (API) to mitigate the consequence of damage, further research is required to develop techniques that predict the ultimate holding capacity of anchors. More information than is presently now supplied, particularly with respect to the soils, needs to be known about the proposed operation site prior to mooring a unit in order to determine this capacity.
- There is a need to instrument some semi-submersibles in order to benchmark the mooring analysis assumptions and methodology. Instrumentation of FPSs currently in use in the Gulf of Mexico present an excellent opportunity to gather this information. (Model test data is not as good as full scale data since there are many inaccuracies associated with modeling an entire mooring system, especially with regard to second order effects.)
- Vital structures in the Gulf of Mexico should be designated (e.g. those that would result in severe environmental or financial loss, should a collision occur). This would

help facilitate future risk studies that could examine specific mooring locations with greater precision and insight.

- A database of blocks which pipelines transit should be created as an aid to drilling contractors or operators in determining locations to moor MODUs.
- There should be some unified and consistent way of ensuring that no MODUs, including jack-ups, operate outside their areas of capability.
- Drilling contractors should be given the facilities within jack-up operating manuals to ensure that they can maximize their units' survival capabilities by being informed of the critical failure mechanisms, and the optimum condition in which to leave the unit.
- Submersibles and jack-ups should not operate in the mudslide areas around the Mississippi delta when conditions are likely to be conducive to mudslide occurrence without a specific study of the failure probability by a recognized mudslide expert.

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CAC/Reports/H3348

APPENDIX

Appendix A - INSTRUCTIONS AND SCOPE

Instructions

These were received by Contract No. 12-35-0001-30745 dated November 1993 from Mr. Charles Smith of the Minerals Manage Service (MMS) to carry out an evaluation of securing procedures for MODUs subject to hurricanes.

Scope

This study will be organized into four tasks:

Task 1 - MODU Failures in GOM Hurricanes - summarize and document the adverse performance characteristics of MODUs in past GOM hurricanes and identify potential performance improvement and consequence damage mitigation measures.

Task 2 - Positioning - based on a study of environmental conditions associated with past GOM hurricanes and the present locations of platforms and pipelines, develop guidelines and recommendations to site MODUs (active and stacked) in areas and in positions where they will do the least harm if they fail to perform satisfactorily.

Task 3 - Mooring Design Criteria - based on a probability based study of environmental conditions and forces associated with past GOM hurricanes acting on two 'generic' semi-submersibles, develop recommendations for the sizing of mooring systems and the definition of emergency deployment systems for floating MODUs.

Task 4 - Manning and Evacuation Planning - based on a computer simulation study of two 'generic' MODUs (one floating semi-submersible, on bottom founded) sited at two different GOM locations and evacuated (fully or partially) using different strategies (helicopter, boat, safe refuge platforms), develop analytical models and guidelines to assist in planning the evacuation and manning of MODUs.

Appendix B - GLOSSARY OF TERMINOLOGY

Reference: API Stationkeeping RP
Cross-references are marked in **bold**

ANCHOR TEST LOAD (PROOF LOAD)

Upon placement of an anchor, it is pulled to a designated load to confirm the anchor is set properly and will not slip prior to this tension level being reached. Industry practice is to pull until the winch stalls, which normally corresponds to 1/3 the mooring line breaking load. This often ties in with the maximum expected operating load. The winches opposite the line being tensioned can be used to impart a higher test load, if required. After the anchor is successfully pull tested, the line tensions are eased to the **pretension** level.

ANCHORS UPLIFT FORCE

Uplift force is obtained by combining the line tension with the angle between the mooring line and the seafloor. If the angle is zero (tangent), the uplift force is also zero: as the angle increases, the uplift force increases.

CATALOG BREAK STRENGTH

The catalog break strength (CBS) is the value a chain manufacture states as the holding capacity of a new chain but is <u>not</u> a guaranteed minimum. Only a small percentage (normally 1%) is subjected to this load, and even then some failures are acceptable. The entire chain is exposed to the **proof load**. The CBS is the nominal line breaking strength typically assumed in a mooring analysis. Caution should be used when evaluating used chain, and inspection or maintenance records reviewed prior to doing so.

COLLINEAR FORCES

Most mooring analyses are based on collinear forces, and are consequently inherently based on the assumption that the wind, waves, and current are coming from the same direction and are commonly used in a mooring analysis. In reality, this is rarely the case and thus, induces some conservatism into most analyses, but for a direction sensitive vessel such as a moored tanker or some large semi-submersibles, larger forces may be produced by non-collinear forces (wind, waves, and current acting from different directions).

DAMAGED ANALYSIS (OR ONE-LINE DAMAGE CRITERIA)

This analysis examines the vessel during the maximum design storm condition with the unit in its equilibrium position following the failure of one mooring system component (e.g., mooring line or thruster). This criteria ensures some redundancy in event of unexpected line failure. In order for this requirement not to be too stringent, a reduced safety factor is allowed as compared to the intact case (intact being all lines undamaged).

DESIGN WEATHER CRITERIA

The maximum design condition is the combined wind, waves and current for which the mooring system is designed. The criteria is normally expressed in terms of the maximum conditions expected to be reached or exceeded, once in a fixed time period such as 5, 10 or 100 years. The owner is normally responsible for selecting such data.

DYNAMIC ANALYSIS

In addition to the static response for a mooring line found with a **quasi-static analysis**, a dynamic analysis includes the mooring lines' fluid loadings effects or **line dynamics**. This requires accounting for the time varying effects of mass, damping, and fluid acceleration on the mooring line, as well as modeling various non-linear effects on the mooring line. A dynamic analysis calculates the wave dynamic tension and combines it with the static tension from the mean plus low frequency offset to find the total tension in the mooring line.

DYNAMIC OFFSET

The dynamic offset accounts for the wave effects on a vessel and is a combination of **wave frequency motions** and **low frequency motions**. Both a **quasi-static** and **dynamic analyses** utilize a dynamic offset (See Appendix D, Quasi-static Versus Dynamic Analysis). Frequency domain (or linearized) analysis can use various methods of combining the wave frequency and low frequency motions. Some less rigorous analysis unconservatively neglect low frequency motions entirely. A total dynamic offset can be obtained from a time domain analysis, but interpretation of the results can be difficult.

HURRICANE CATEGORIES

Category	Winds (kts)
1	64-82
2	83-96
3	97-113
4	114-135
5	> 135

LINE DYNAMICS

Line Dynamics includes the effects of line inertia and the direct fluid loading on the line. Tensions are formed in addition to those computed by a quasi-static analysis when the line is unable to instantly adopt to a new shape as the vessel moves. As the resistance of the water slows the movement of the line, the line must stretch to allow the vessel to move under wave action. This induces an extra tension and is designated as wave frequency tension.

LOW FREQUENCY DAMPING

The magnitude of low frequency damping is difficult to quantify. In cases where low frequency motions are large or for a stiff mooring system (i.e. shallow water) where small motions can produce large tensions, the maximum line tensions are highly dependent on the magnitude of low frequency damping. There are primarily three sources of damping:

- Hull Viscous Damping - Viscous damping results from friction forces caused by the movement of the hull through water. The amount of viscous damping is highly dependent on the quantity of current in-line and normal with the low-frequency motions. Damping effects of vortex shedding are often included in this category. This area is the most understood source of damping and often the only effect considered in a mooring analysis.

- Wave Drift Damping - The waves produced by the hull moving through water generate **wave drift forces** and make up part of the overall damping force. This source is also dominated by the interaction of **low frequency** and **wave frequency** motions. It is difficult to quantify due to the small magnitude of the forces involved, but model tests indicate the effect is of a similar magnitude to viscous damping and increases with the square of wave height.

- Mooring System Damping - The resistance forces of the mooring lines moving through fluid induce a damping effect. Model tests predict this effect is most significant between water depths of 1000 feet and 2000 feet.*

It is important to note that the absolute magnitude of the low frequency damping force is extremely small, as is the low frequency exciting force. Small errors in calculation can, therefore, lead to large errors in effect.

LOW FREQUENCY MOTIONS

Low frequency motions of a vessel are induced by second order or low frequency wave forces. It is especially prevalent in the horizontal plane of motion (i.e. surge, sway, and yaw). There the mooring system is the only restoring force and acts as a large weak spring. Since all springs have a natural frequency where resonance occurs, the small second order wave forces occurring at the mooring systems natural frequency can produce correspondingly large motions and thus high line tensions. Factors affecting the magnitude of the low frequency motion are:

- System Mass and Added Mass.
- Mooring System Stiffness - Determines the natural frequency of the system.
- Low Frequency System Damping - Determines the amount of amplification of motions.

The greatest uncertainty associated with a mooring analysis is in determining the low frequency motions. Methods for predicting the magnitude of these motions are still in development, especially those methods concerned with determining the amount of **low frequency damping**. Tables are included in the API RP to estimate low frequency motions when no other means are available; however, the tables are only valid for vessels below 30,000 short tons.

Gusting wind acting upon the vessel also induces low frequency motions. The API RP contains allowances for including wind generated low frequency motions.

* "Mooring Line Daming - Summary and Recommendations," FPS 2000 Mooring and Positioning, Part 1.5, Marintek, 1992.

MEAN OFFSET

Mean offset is the vessel motion produced by the combined effects of wind, **wave drift** and current forces. The offset is modeled as a step motion due to the forces being statically applied at the maximum design conditions. Generally, the forces are assumed to be **collinear**.

OFFSET LIMIT

Offset limitations are generally defined by vessel excursion from the center of the moorings. The excursion of the semi-submersible is of great importance when connected to a wellhead or adjacent to another structure. Such limitations as listed below should be considered:

- Minimum allowable platform/vessel clearances
- Personnel bridge operational capabilities
- Minimum allowable platform/anchor line/pipeline clearances
- Umbilical operational capabilities
- Marine riser operational capabilities

The amount of excursion is of little importance when the semi-submersible is stacked.

PRETENSION

The pretension load is the tension in the mooring line without any environmental loadings. This load is generated by winching in the lines until the desired tension is reached. A high pretension is beneficial in the operational mode since it increases the stiffness of the mooring systems and thus can reduce the mean and dynamic offset of the vessel. Also, a pretension may be set to maintain a mooring line in suspension over subsea equipment. It is generally assumed that any level of pretension will increase the storm induced mooring line tension levels, and because of this, lines are often slacked during heavy weather.

PROOF LOAD OF CHAIN

The load to which the entire chain is subjected prior to delivery, normally 70 percent of CBS. The intent of this proof load is to:

- Demonstrate a minimum load that the entire chain is capable of sustaining.
- Plastically deform the chain so that the stud is "set".
- Leave residual compressive stresses in the areas subjected to in service tensile fatigue loads.

QUASI-STATIC MOORING ANALYSIS

A quasi-static analysis approach requires that the loads due to the steady state effects (i.e., wind, current, mean wave drift) are first applied to a non-linear stiffness model of a mooring system in order to determine the **mean offset.** The maximum horizontal **dynamic motions** are then applied to the vessel in its offset position and the resultant line tensions are calculated using a static catenary (non-linear) analysis computer program. According to API RP, the wave motions consist of both wave frequency and low frequency induced motions, although, many quasi-static analyses (including those conducted to DNV's POSMOOR) neglect low frequency motions for semi-submersibles.

RELIABILITY ANALYSIS

A reliability analysis is based on probabilistic methods which model various uncertainties to obtain a logical and objective quantification of risk or system failure.

SEMI-SUBMERSIBLE GENERATIONS

The semi-submersible fleet can be divided into four generations as follows:

Generation Classified	Year Delivered	Deck Load (tonnes)	Water Depth Rating (feet)
1st	Before 1972	1200-1600	600-800
2nd	1972-1979	1600-2500	600-1200
3rd	1980-1984	2600-3500	1200-2000
4th	After 1985	3500-5000	2000-6000

The first generation, such as the three column Sedco 135 and five column Pentagone Class, was based on designs developed prior to 1970. The second generation featured increased displacements, parallel pontoons, centered drilling systems and rectangular deck structures. Examples of these are the Aker H-3, Sedco 700 Series and Ocean Victory Class. Third and Fourth Generation are based on designs after 1980. They are generally larger than second generation vessels, are designed to operate in deeper and more hostile environments and comply with the regulatory changes adopted in the North Sea in the late 1970's.* A good example of a third generation semi-submersible is an Enhanced Pacesetter and the Trendsetter for the fourth generation. The most significant change

* D'Souza R, Henderson A, Barton D, Hardin D, Boyd A, Solberg I, "The Semisubmersible Floating Production System: Past, Present, and Future Technology," Proceeding from SNAME Centennial Meeting, 1993.

taken place between the third and fourth generation semi-submersibles is in drilling equipment technology which has necessitated large increases in payload and doubled their total size compared to the early second generation semi-submersibles.

SURVIVAL MODE

A semi-submersible is placed in survival mode when it is expected to exceed its operational limits. Typical actions required to enter this mode are:

- Decrease Draft - This increases the air gap of the MODU.
- Disconnect Riser - May enable **offset limits** to be disregarded.
- Slacken Lines - Reduces the tension levels in the most loaded lines.

THRUSTER ASSIST

For manned mobile units, mooring procedures allow the effect of thrusters to be incorporated in the simulation of some mooring situations, if personnel are onboard to operate the system. The thrusters are used to counter the wind and current effects and its thrust is subtracted from the mean load.

TRANSIENT ANALYSIS

A transient analysis is conducted to determine the maximum line tensions and vessel excursions after a single line failure. Calculations are based on time domain methods and model the overshoot as the vessel moves from one equilibrium position to another after a line failure. The drag, inertial and added mass properties of the vessel must be considered in the calculations. Transient analysis can be important for certain to determine the minimum safe clearance, such as when operating adjacent to a fixed platform.

WAVE FORCES

As a series of waves pass by a floating vessel, the resulting forces can be broken up into the following three categories:

- First Order Forces - induce the high or **wave frequency motions** and occur at the same frequency as the wave themselves. They are the result of orbital motions normally (c.f. a cork moving in a wave).
- Second Order Forces - are generated by the reflected energy from a wave passing by a vessel. These forces occur at frequencies well below that of the wave frequency, and thus the motions induced in a moored system are called **low frequency motions**.

- Wave Drift Force - is the average of the steady components of the second order or low frequency wave forces. It is assumed to be a constant steady force in the same manner as the wind and current forces.

WAVE FREQUENCY MOTIONS

Wave frequency motions are those motions caused by the first order wave forces. These motions can be determined by a number of analysis programs which produce Response Amplitude Operators (RAOs) for a given vessel. The RAOs can then be integrated with an irregular sea spectrum to quantify vessel wave frequency motion.

WINCH POLICIES

Since semi-submersibles in the Gulf of Mexico are evacuated on the forecast of a hurricane, the only winch policy available during hurricanes is a passive or all lines slack policy. Several other options are available to manned vessels during storm conditions:

- Passive - Mooring system set-up with initial working tensions and no subsequent winching actions are undertaken. In the Gulf of Mexico, a passive winch policy is used in that normally all lines are slackened prior to evacuation.

- Leeward Line Slackening - Leeward lines can be slackened to reduce the tension to a minimum to ease the windward line tensions. This policy requires the winches to be adjusted as the wind direction changes and thus generally requires the vessel to be manned.

- Full Active Optimization - This option assumes that unrestricted winching of both windward and leeward lines can be undertaken for the sole purpose of reducing the maximum line tensions. Windward lines adjacent to the most loaded line are winched in so that they can carry more of the load. Alternatively, the most loaded line can be winched out.

Appendix C - GUIDANCE TO SITE SPECIFIC MOORING ANALYSIS

1.0 Background

The purpose of this appendix is to provide a general understanding of the analysis used to evaluate a MODU's mooring system. It provides a simple interpretation of current practices and of the draft version of API Recommended Procedures (RP) "Design and Analysis of Stationkeeping Systems for Floating Structures" dated May 1, 1994, but is not intended to be all inclusive.

The aim of any mooring analysis is to predict the behavior of the anchoring arrangement in critical conditions and to determine if it can comply with an appropriate acceptance criteria. Assessment criteria are applicable to both the operational and survival conditions. The primary areas of interest are listed below:

Line Tensions:	Line factors of safety, anchor capacity
Vessel Excursions:	Operational limits and clearances with other installations.

2.0 Information Required

For a mooring analysis to be undertaken or reviewed, various details concerning the MODU and its mooring equipment are required.

Line Data:

- Type (Number and type of elements in line; e.g., chain, wire rope, manmade fiber)
- Length (useable)
- Minimum quoted breaking strength
- Axial Stiffness (if unknown, recommended values available in API RP)
- Underwater weight/unit length
- Number of lines available
- Presence of any mid-line buoys (surface/sub-surface, net buoyancy, etc.)

Vessel Data:

- Environmental coefficients for the calculation of environmental loads and motions
- Position of fairleads (i.e., bearing and distance from unit center and height above keel)
- Survival and operational displacements
- Principal dimensions

- Survival and operating draft
- Thrusters' details, if they are to be used (number, type, capacity)
- Anchor details (type and size)
- RAOs for motion assessments

Site Data:

- Water depth
- Soil type (if available)
- Seabed slope
- Adjacent structures
- Weather data

3.0 Selection of Design Criteria

3.1 Environmental Criteria

Generally expressed as the maximum wind, wave, and current that is expected to be reached or exceeded once during a designated return period. A risk analysis study may be used to determine the required return period, but the RP states that it may not be less than the following:

Maximum Survival Condition	Design Return Period
• Operating in Isolated Area	5 years
• Operating in Close Proximity to Another Structure	10 years
• Operating in Tropical Revolving Storm Areas	Determined by risk study but no less than 1 year
Maximum Operating Condition	As determined by Owner

Note: The Maximum operating condition is generally limited by the riser system, expressed as the maximum permissible vessel offset. This criteria should be set low enough to enable the operating personnel sufficient time to disconnect the riser during worsening weather conditions, but high enough to minimize unnecessary downtime.

The maximum operating condition is not intended to be used to evaluate the overall safety of the mooring system since the MODU is evaluated to the higher survival criteria for the purposes of safety.

3.2 Design Conditions

Type of Mooring	Analysis Method	Conditions to be Analyzed
• Away from other structures	Quasi-static or Dynamic	Intact
• Mooring lines over pipeline	Quasi-static or Dynamic	Intact/Damaged
• Vessel next to platform	Quasi-static or Dynamic	Intact/Damaged/ Transient

For MODU operations, the option exists of conducting either a quasi-static or dynamic analysis. The quasi-static is simplistic in approach and has been the standard of mooring analysis for the past 20 years. Because of its simplicity and potentially serious lack of conservatism, a higher safety factor is required with a quasi-static analysis. A quasi-static analysis may not be appropriate in all cases.

4.0 Environmental Forces

4.1 Basic considerations

The forces on the vessel have two components; static steady-state forces and dynamic forces. This section will examine the steady-state forces made up from wind, current, and waves.

4.2 Wind Forces

The steady-state wind force (F_w) can be determined by using equation 4.1.

$$F_w = C_w V_w^2 \qquad (4.1)$$

C_W = Wind force coefficient
V_W = Wind speed

The wind force coefficient can be determined from model tests or from calculations using projected areas, shape and height coefficients. This value is dependent on wind direction with respect to the vessel, such as from the bow, quarter, or beam.

There are two options of average wind speed to use in this formula.

a. 1-minute average wind speed.

b. 1-hour average wind speed.

If the lower 1-hour average wind speed is used to determine the steady-state wind force component, the dynamic motions must account for increased low frequency oscillations due to a fluctuating wind force. The API RP states that the choice of which option to use depends on the system parameters and goals of the analysis. Either approach may give more severe loads, depending on the moored system and the dynamic wind spectrum used.

4.3 Current Forces

The steady-state current forces (F_{curr}) can be determined using equation 4.2.

$$F_{curr} = C_{curr} V_{curr}^2 \qquad (4.2)$$

C_{curr} = Current force coefficient
V_{curr} = Current speed

The current coefficient (as with the wind force coefficient) is determined by either vessel model test results or calculations combining the projected areas and drag coefficients of the vessel's hull.

In general, current speed is the referenced at the surface of the water. In deeper waters, current forces on the riser and mooring lines become important. The area and drag coefficient of these systems and a current speed versus water depth profile should be used.

4.4 Wave Drift Forces

The drift force is obtained from the steady component of the second order dynamic wave forces. The drift force can be determined from model tests or motions analysis computer programs. The API RP does include curves for quickly determining wave drift forces when no other means are available, but the use of these curves is not recommended for semi-submersibles with displacements of over 30,000 short tons.

5.0 Analysis Procedure

5.1 Introduction

Once the environmental forces on the semi-submersible, and the mooring system characteristics (such as mooring pattern, line length and pretensions) are known, the mooring system can be analyzed. API offers the option of performing a quasi-static or dynamic analysis for MODUs. A quasi-static analysis is simplistic but requires a higher factor of safety than the dynamic analysis. The dynamic analysis uses the same basic approach as the quasi-static method but also accounts for vertical motion of the fairleads, dynamic effects of fluid loading on the mooring lines, and other non-linear considerations.

5.2 Quasi-Static Analysis

A quasi-static analysis involves applying the steady-state environmental loads to the semi-submersible and calculating the horizontal displacement of the vessel (i.e., mean offset) using catenary analysis techniques. Most modern programs properly account for mooring line stretch. The wave frequency motions and low frequency motions are calculated and added to the mean offset. From this maximum offset, the mooring line tensions are calculated and compared to the maximum allowable load. The anchor load is determined and compared to the anchor load holding capacity. A general overview of a quasi-static analysis is shown on Figure C-1.

5.2.1 Mean Offset

The mean offset is the vessel motion produced by the combined effects of wind, wave drift and current forces. The offset is modeled as a step motion due to the forces being statically applied at the maximum design conditions. Generally, the forces are assumed to be collinear. It is not uncommon for this to be the extent of some simple mooring analyses.

5..2.2 Wave Frequency Motions

The vessel's Wave Frequency Motions can be calculated from either model test results or a motion analysis program. Using either method, the response amplitude operators (RAOs) of vessel motions versus wave frequency are obtained. These RAOs and an appropriate wave spectrum, are integrated to obtain a response spectrum from which the maximum and significant Wave Frequency Motions are obtained.

These wave frequency motions are normally a function of the vessel properties and water depth, and are independent of the type of mooring system used, but in very shallow water, the stiffness of the mooring system can have an effect on the RAOs and should be accounted for.

5.2.3 Low Frequency Motions

The low frequency wave motions are caused by resonance between the mooring system, as it acts as a spring, and the low frequency wave exciting forces. Because of resonance, a relatively small force can be magnified into a large motion, so the low frequency motions are an important factor in determining mooring line tensions.

The determination of low frequency wave motions requires model tests or a motions analysis program. The draft API RP states that methods for predicting low frequency motions are still in development. Current practices involve modeling a simple single degree of freedom mass-spring system. This method requires knowledge of the vessel mass, system stiffness, and system damping. The stiffness is obtained from the mooring system stiffness when at the mean offset.

As with wave drift force, there are curves contained within the API RP to estimate low-frequency motions. These are for a typical semi-submersible but are not recommended for semi-submersibles with displacements over 30,000 short tons.

If the effects of oscillating wind force, also called low frequency wind force, are to be included, the resultant motion can be combined with the low frequency wave motions calculated in this step. Oscillatory wind induced motions are calculated like low frequency wave motions. While the is no generally accepted wind spectral shape, such as exists for waves, the Draft API RP provides a simple spectrum.

5.2.4 Maximum Offset

The maximum offset is the mean offset plus appropriately combined wave frequency and low frequency vessel motions. The maximum offset can be determined by the greater result from the following equations:

$$\text{Maximum offset} = \text{Mean offset} + WF_{max} + LF_{sig} \qquad (5.1)$$

or

$$\text{Maximum offset} = \text{Mean offset} + WF_{sig} + LF_{max} \qquad (5.2)$$

where WF_{max} = Maximum wave frequency motion

WF_{sig} = Significant wave frequency motion

LF_{max} = Maximum low frequency motion

LF_{min} = Significant low frequency motion

If this analysis is using the maximum operating environmental criteria, the calculated maximum offset must be less than the allowable offset. The allowable offset is normally determined by a drilling riser stress analysis, and typically ranges from 2% to 4% of water depth.

5.2.5 Maximum Line Tension

The maximum line tension is calculated at the maximum offset using a static mooring analysis program in the same manner the mean line tension is obtained.

Applying the appropriate factor of safety, the maximum tension must be less than the nominal breaking strength of the wire or chain. For a new chain or wire, the nominal breaking strength is taken to be the same as the catalog breaking strength. For a used chain or wire line, this break strength may appropriately be reduced.

The following are factors of safety and applicable condition:

Mooring System Status	MODU Next To Platform		MODU Over Pipeline		MODU Away From Other Structures	
Analysis Method	Quasi-Static	Dynamic	Quasi-Static	Dynamic	Quasi-Static	Dynamic
Intact	2.0	1.67	2.0	1.67	2.0	1.67
Damaged	1.43	1.25	1.43	1.25	N/A	N/A
Transient	1.18	1.05	N/A	N/A	N/A	N/A

5.2.6 Holding Power of Anchoring System

Drag anchors are commonly used for floating MODUs. Anchor holding power is dependent on anchor type, size, soil conditions, anchor penetration, type of anchor forerunner. Estimation of holding power can be obtained from tables found within the API RP. The friction of chain or wire on the sea floor bottom will also increase the holding power of the anchor and should be included.

For the intact condition, the anchor load is calculated at the maximum offset and factor of safety applied and compared to the holding power of the anchor and line on the bottom. The anchor factors of safety for MODUs are as follows:

Quasi-static Analysis	1.0
Dynamic Analysis	0.8

Drag anchors are generally designed to withstand forces in the horizontal direction and any vertical or uplift force may cause a reduction in holding power. To prevent anchor uplift force, sufficient line length is deployed to ensure that that the there is at least some lying on the sea floor next to anchor. The latest generation of drag anchors has shown a resistance to uplift force, and the draft API RP will allow some uplift if it can be demonstrated that the anchor can hold in such conditions.

5.3 Dynamic Analysis

5.3.1 Introduction

A dynamic analysis accounts for the time varying effects due to mass, damping, and fluid acceleration on the mooring line as well as the vertical and horizontal fairlead motions in calculation of the line tensions.

A dynamic analysis can use two different approaches; a time domain analysis or a frequency domain analysis. The time domain models non-linear effects by updating all the variables such as mooring line stiffness, mass, damping in each time step of the analysis. While this is an accurate representation of the forces on the mooring line, it is very complex and time consuming. Computer capability is a limiting factor. In the frequency domain method, the non-linear effects are converted to equivalent linear models and analyzed in the linear frequency domain.

5.3.2 Frequency Domain Analysis

A frequency dynamic analysis employs the same methodology as the quasi-static analysis. The mean offset and low frequency motions are computed in an identical manner to the quasi-static manner. The vessel is then moved to the mean offset position plus the significant low frequency motion value where the line tension is computed. From there, the wave frequency tensions are calculated using a dynamic mooring program with the vessel motions as input. Total line tension is calculated by the following equation.

$$T_{max} = T_{mean} + T_{LF\,sig} + T_{WF\,max} \qquad (5.3)$$

T_{max} is the maximum line tension

T_{mean} is the mean line tension

$T_{LF\,sig}$ is the line tension due to the significant low frequency motions

$T_{WF\,max}$ is the line tension due to the maximum wave frequency motions

Then the vessel is moved to the mean offset plus the maximum low frequency motion value. Again, the wave frequency tensions are calculated using a dynamic mooring program. The total line tension is computed according to equation 5.4. Then the maximum line tension is the larger tension from equations 5.3 and 5.4.

$$T_{max} = T_{mean} + T_{LF\,max} + T_{WF\,sig} \qquad (5.4)$$

$T_{LF\,max}$ is the line tension due to the maximum low frequency motions

$T_{WF\,max}$ is the line tension due to the significant wave frequency motions

The appropriate factor of safety, from section 5.2.5, is applied to the maximum tension and must be lower than the nominal breaking strength of the mooring line.

5.3.3 Time Domain Analysis

The same basic sequence of calculations is conducted in the time domain analysis as the frequency domain analysis. The only difference is in the way the maximum and significant wave frequency motions are calculated. Since the time domain calculation is computed over a finite interval of time, and there are an infinite number of possible wave height sequences that could be encountered, there is no guarantee that the statistical maximum and significant values will not be generated by the analysis. The draft RP gives various methods of determining the maximum and significant values.

5.3 Transient Analysis

When a vessel is to be moored in close proximity to a fixed platform, a transient analysis should be conducted to demonstrate that if one line breaks, the resulting maximum transient motion or overshoot meets the minimum clearance to the platform. A time domain solution is required to determine the maximum offset A mooring analysis program would solve for the maximum offset using the basic equation governing the transient motions as follows:

$$(M + A)\ddot{X} + C\dot{X} + KX = F_m + F_w + F_l + F_o \qquad (5.5)$$

where X = Displacement
M = Mass
A = Added mass
C = Damping coefficient
K = System stiffness
F_m = Steady (mean) force
F_w = Wave frequency force
F_l = Low frequency force
F_o= Out of balance mooring load due to one line breaking

5.5 Operator Interactions with Mooring System

5.5.1 Background

The mooring procedures allow certain operator actions, such as winch adjustments or thruster assistance, to reduce tensions on the mooring lines. Requirements for allowing this are that the practice must be well defined in the operations manual and is routinely carried out by trained operations personnel. Clearly, it also requires the platform to be manned.

5.5.2 Thruster Assistance

Thrusters may be applied to resist the steady environmental forces and thus reduce the steady-state or mean load. The draft RP code provides the following guidelines in applying thrusters:

Mooring System Status	Manual Thruster Control	Automatic Thruster Control
All lines intact	70 % of net thrust after failure of any one thruster	Net thrust after failure of any one thruster
One line broken	70 % of net thrust from all thrusters	Net thrust from all thrusters

5.5.3 Winch Policy

It is common practice for operators to slacken the leeward mooring lines in order to reduce tensions on the windward lines. Several operations manuals dictate adjusting tensions in the windward lines to optimize line tensions but, this is not common practice and has often not been successfully implemented. The draft RP does not allow the use of optimizing windward tensions unless special circumstances exist, but does support slackening the leeward lines when manned.

Within the Gulf of Mexico, during an impending hurricane, it is common practice to slacken all lines prior to evacuating the vessel. The draft RP states that this operational practice should be taken into account in the mooring analysis.

Figure C-1

Method of Conducting a Quasi-Static Analysis

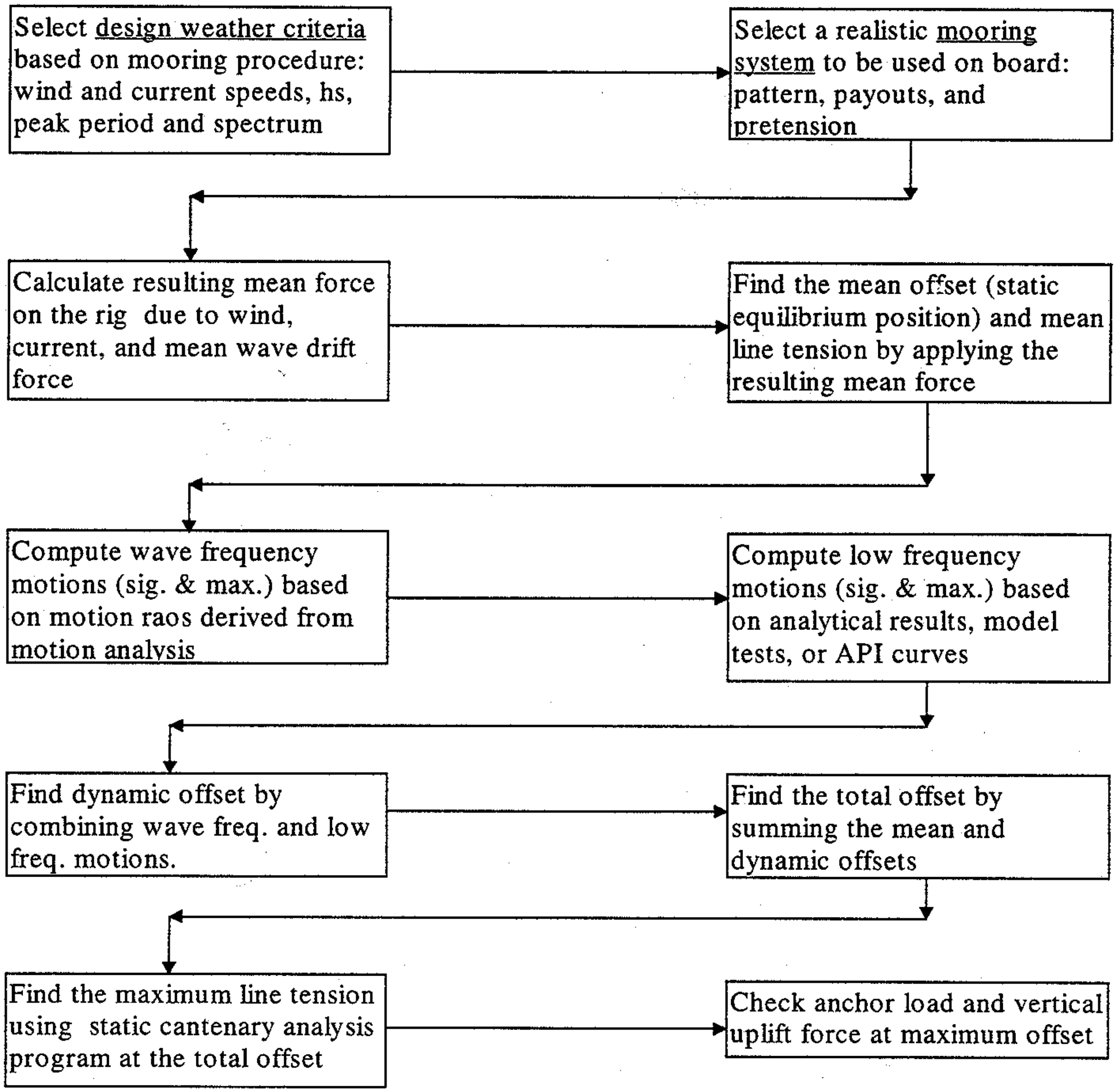
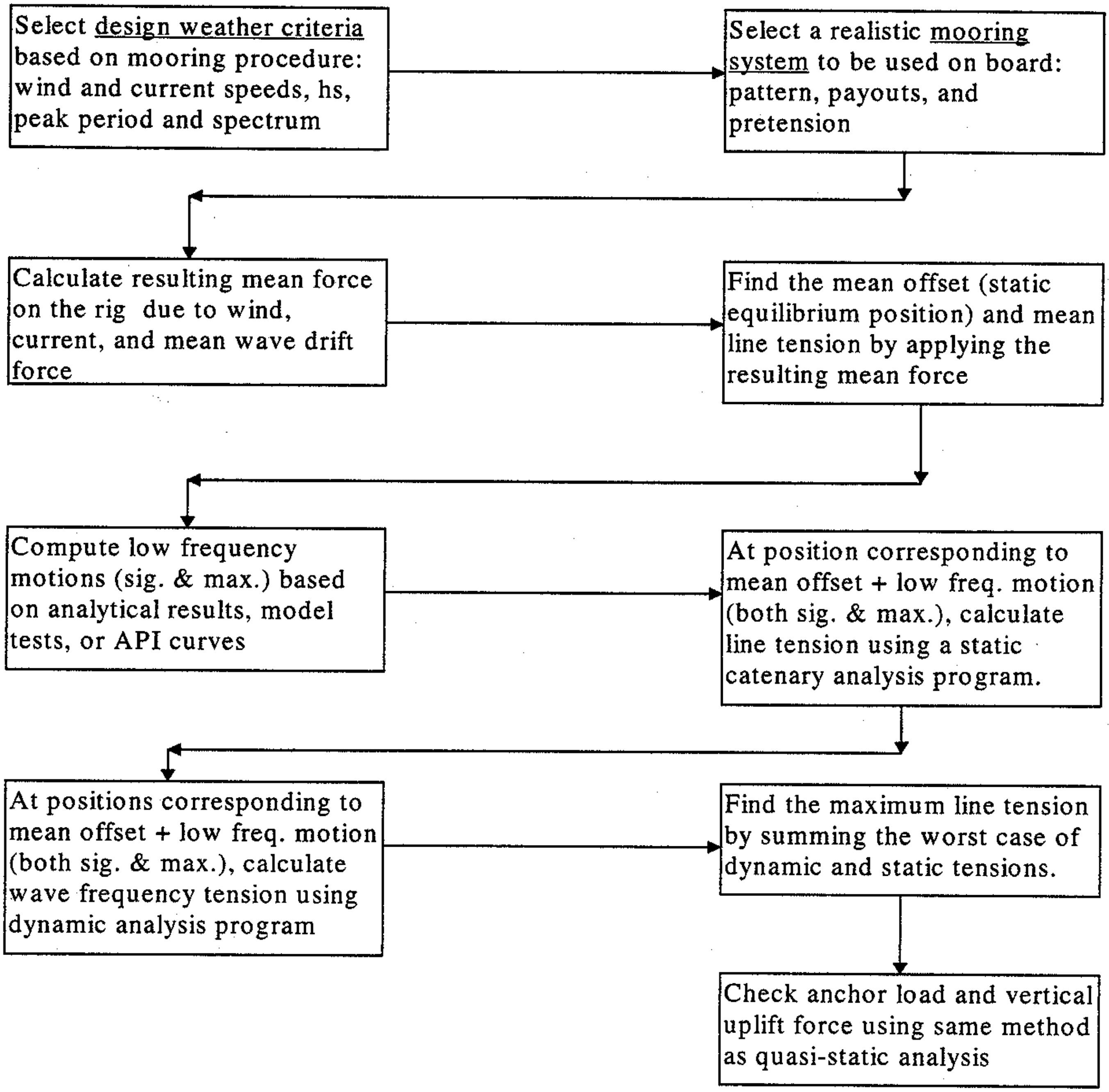


Figure C-2

Method of Conducting a Dynamic Analysis



Appendix D - COMMENTARY ON MOORING ANALYSIS COMPONENTS

ANCHOR HOLDING POWER

In general, an anchor's holding capacity is designed to be less than the breaking strength of the mooring line so that an anchor will drag prior to a mooring line breaking.* The theory is that when conditions exceed those for which the vessel is designed, a small amount of anchor drag will result. This produces a favorable redistribution of loads among the mooring lines, thus reducing the peak line tension, and improves the mooring system's ability to survive larger storms. The difficulty of applying this concept is in accurately determining the difference between the proof load and the ultimate holding capacity of the anchor.

Anchor Holding Capacity

The most prevalent method to calculate anchor holding capacity is to extrapolate from empirical tests conducted by the Navy.[1] The Navy has produced tables which contain various types of anchors and relate anchor mass to maximum holding capacity, for both soft and hard soil conditions. Problems can arise since these tests were done for a broad category of soil types, and actual performance can vary significantly due to the variation with on-site soil conditions.[2] Often, the specific soil conditions are unknown until moving onto a location, making accounting for any variation impossible. Other variables, such as the fluke angle, difference between static and dynamic holding capacity, type of lead line to the anchor (chain vs. wire), time anchor has been embedded (soaking), and vertical loading of the anchor, also have an impact on the holding capacity of an anchor.[3] There are anchor holding capacity computer programs[4] which account for many of these factors, and their capabilities are improving, but they still have a long way to go before they will be able to consistently predict holding capacities for different soil conditions.

Anchor Proof Load

To validate holding capacity estimates, the anchors are pull tested when on-site. Even then, the actual capacity will normally not be determined, only a somewhat arbitrary proof load. Ideally, the pull test should be to the maximum calculated anchor load under

* This assumes that there are no nearby subsea structures that could be damaged by a dragging anchor.

design conditions to ensure reliability of the mooring analysis.[3] The test load is often less than this for operational reasons such as limited winch capacity or the drilling contractor's reluctance to subject the lines to such high tensions.[5] With high efficiency anchors in soft soils, a high test loading may cause the anchor to penetrate too deeply making recovery of the anchor difficult. For these reasons, the actual proof load is often lower than the maximum design condition, and a minimum acceptable pull test load is the expected maximum tension under operational conditions.[•]

Vertical Uplift

To reduce the chance of premature anchor drag, mooring procedures traditionally require there be no vertical uplift force on the anchor which may reduce the horizontal holding capacity and can unseat the anchor. The codes accomplish this by dictating that the mooring line must be tangential to the seafloor at the anchor. New high efficiency anchors, which are becoming prevalent in the industry, have shown a good resistance to vertical uplift force.[6] Taking this into account, API is giving some allowance for vertical uplift force in its new Station Keeping RP.

It is noteworthy the post incident mooring analysis in Appendix F, showed a significant amount (300 kips) of vertical uplift force at the anchors. Since the *"ZANE BARNES"'* most loaded anchors did not drag, the restriction of no uplift force appears excessive. The limited experience from Hurricane Andrew seems to support new provisions in the draft API Station Keeping RP which make some allowance for anchor uplift.

CONDITION DURING ABANDONMENT

Typically, a drilling contractor will slack all lines to minimum values prior to evacuation to enable the system to better absorb the hurricane loads. Noble Denton has conducted various sensitivity analyses[†] showing that the optimal value is somewhat higher than the minimal load and is a function of the mooring system deployed and water depth. The benefit is due to the dependency of dynamic tensions on the pretension level. For example, a greater pretension level produces a stiffer system and can lead to lower tension levels resulting from low frequency motions especially in shallow water.

[•] Anchor dragging under operational loads can have serious consequences such as the overload of the riser and ball joint.

[†] These analyses were based on a collinear environment which was assumed to produced the greatest tensions. It may be argued that an all-line -slack policy results in a greater benefit when considering a non-collinear environment, but present analysis methods are not capable of predicting the magnitude of this benefit.

CONSEQUENCE OF FAILURE

Historically, MODU mooring systems have been subjected to much less regulatory and review compared to FPS or fixed platforms due to a lesser consequence from a resulting failure. The most obvious reason for this reduction is the lack of hydrocarbon processing onboard MODUs. Other factors often used to justify this reduction are summarized in the following list, but the assumptions used to support these may not always be true.

1) Shorter Exposure to Weather Extremes. With on station periods of less than a year, the likelihood of the vessel encountering its design criteria is minimal. But, the design life of a MODU is similar to that of an FPS, and over that life, the likelihood of encountering the design weather would be the same.

2) Mobility of MODUs. This allows for them to be relocated prior to encountering weather greater than designed to. But, vessels often do not move due to various reasons such as difficulty in predicting storm track, distance to shore, or lack of support vessels.

3) Periodic Mooring Line Inspection. Frequent moves allow visual and NDT inspections of the mooring chain and wires for corrosion and broken components between retrieval and deployment of lines. But, current inspection methods are inadequate to guarantee the lines free of defect and several semi-submersibles with recently inspected and repaired lines had mooring failures during a North Sea storm in 1990.[7]

4) The resultant damage would be small. Should a failure occur, little or no consequence should result. For example, if tensions exceed their design limits, the only consequence is a small amount of anchor drag. But, in Hurricane Andrew, several drifting MODUs whose moorings failed caused severe damage to structures many miles away.

DESIGN RETURN PERIOD

Definition of a Given Period.

The specification of a design return period in the Gulf of Mexico is insufficient to ensure a uniform standard since significant differences exist among the values quoted by different meteorological consultants and used by many MODU assessors for the same stated return period.[8]

Site Return Period vs. Area Return Period

When examining design return periods, it should be mentioned that a site specific maximum for a given return period is different from an area maximum for a region such as the Gulf of Mexico. For instance, Hurricane Andrew was a category 4 hurricane of which there have been 18 of equal or greater strength to enter the Gulf this century, so this could roughly termed a 5 year hurricane for the region. For some of the specific blocks that Andrew affected, this was the only hurricane of this magnitude to pass through this century. For those sites, Andrew was approximately a 100 year event. The greater the population of semi-submersibles in the Gulf at any given time, the greater the probability that any one vessel will encounter its site specific design limit. This is a different concept than in the North Sea where the storms are not as path restricted.

Also, site specific environmental maximas are governed by the proximity to historical paths of hurricanes. Since there has been only a limited number of category 3 or greater hurricanes, it is difficult to predict the future path of such a hurricane by examining past hurricanes. Some weather extreme hindcast methods use a random path generator to determine site maximums: others use a historical weighted path generator maintaining that there are preferred tracts for these hurricanes. What is an appropriate method still in controversy by the experts in the field.

QUASI-STATIC VS DYNAMIC ANALYSIS

The quasi-static analysis is widely used within the industry for the mooring analysis of MODUs because of its simplicity. Care should be taken whenever applications are outside previous experience since a quasi-static analysis can produce inconsistent results when compared to a more rigorous dynamic analysis.[9] Normally, any inherent errors are accounted for by the larger safety factor required in the acceptance criteria when a quasi-static analysis is used, but as exploration extends into deeper water, a quasi-static analysis may be less appropriate. Currently, API does not state the limitations of a quasi-static analysis, but DNV does require all mooring analyses for systems in greater than 1500 feet to be dynamic.

A dynamic analysis is more computationally cumbersome than a quasi-static analysis and thus, requires a greater amount of computer time to complete. With advances in analysis programs and desktop computer capabilities, however, a sophisticated dynamic analysis is no longer time restricted.

The current understanding of what is meant by a dynamic analysis is often confused since there are several dynamic analysis techniques available. Commonly, a dynamic analysis requires that the time varying effects of mass, damping, and fluid acceleration on the mooring line, as well as modeling various non-linear effects on the mooring line be accounted for. It is the degree to which these non-linear effects are accounted for which produces the variation among different dynamic techniques. The four primary nonlinear effects are:

- Nonlinear Stretching of the Line - Typically important only to synthetic materials such as nylon. Chain and wire can be assumed to behave linearly.
- Large Catenary Shape Changes - The geometric non-linearity associated with large changes in shape of the mooring line and, the motions of the fairleads should be included.
- Fluid Loading - The Morison equation is most frequently used to represent fluid loadings on mooring lines. The drag force on the line is proportional to the square of the velocity (between the fluid and the line), hence non-linear.
- Bottom Effects - The interaction between the line and the seafloor is a frictional process and because the length of grounded line constantly changes, is thus non-linear.

As mentioned in Appendix B, both quasi-static and dynamic analyses have various meanings in the industry. Because of the confusion between these definitions of "dynamics", care must be used when commissioning or reviewing a mooring analysis. Some mooring analyses and mooring computer software literature state they include "dynamics", implying they utilize the most up to date line dynamic techniques. Upon investigation, the "dynamics" term actually refers to the dynamic motions found in a traditional quasi-static analysis. This can also lead to inappropriately applying the reduced safety factors for use of line dynamics, to a quasi-static analysis.

LOW FREQUENCY MOTIONS

Inclusion of low frequency motions for semi-submersibles is required to adequately predict mooring line tensions.[3] Many quasi-static analyses conducted today do not account for these motions. Neglecting low frequency motions can significantly underpredict the line tensions, especially for large 4th generation semi-submersibles. In a worst case situation,* low frequency motions can account for over 25 percent of the

* Worst case being a large semi-submersible or moored ship with a stiff mooring system in shallow water.

total line tensions. Accurately predicting low frequency motions is very difficult. Use of standard API tables for smaller vessels, mooring analysis programs, and model tests are the most common methods of doing so.

API Tables

As an aid to MODU assessors, API RP 2P included curves to allow assessors a means to quickly approximate low frequency motions and wave drift force for semi-submersibles and ship shaped vessels when no other means are available. The curves were developed prior to 1987 using a motions analysis computer modeling typical designs in existence at the time. After these curves were established, much larger fourth generation semi-submersibles came into service with very different wave drift loading characteristics than the semi-submersibles the API curves are based on. Use of these curves for a large semi-submersible can significantly underestimate the forces in its mooring system. The new draft API Station Keeping RP explicitly states that the curves should not be used on semi-submersibles over 30,000 short tons. Prior to this, it was not generally known what limitations were associated with the use of these curves.

Computer Models

Predicting the magnitude of low frequency motions has a high degree of uncertainty. Since these motions are a function of resonance, they are very sensitive to damping. Current tools to predict damping, and thus the magnitude of motions, vary widely. One comparison done for the FPS 2000 Joint Industry Study[10] found large variations between mooring analysis programs results when analyzing the same set of data. For example, the study found a range of computed low frequency motions from 0.77 meters to 10.5 meters for the same vessel. While there has been a great deal of fundamental research into low frequency motions, the industry still lacks a rigorous analytical tool to adequately predict these motions.

Model Tests

Calibration of low frequency motion predictions using model tests does not avoid the uncertainty. The periods of these motions are so long and exciting forces so small, that the model basin cannot ensure second order basin effects are not present. Detailed modeling of the mooring lines may be critical. One possible solution would be to analyze the scale model within the basin, and try to get some level of calibration with full scale tests.

MOORING LINE LENGTH

Mooring lines should have sufficient length such that a mooring analysis satisfies any appropriate safety factors and prevents anchor uplift.* There are some differences between DNV's and API's approach as to which condition is analyzed in regard to anchor uplift, and this is described in Appendix E. In regards to the maximum deployable length, the following restrictions apply:

- Must maintain a sufficient allowance in the locker to account for winching operations such as pull-off for of a blowout, slacking lines, moving about in the operational mode and any unusable length that remains in the chain locker.
- Winch capacity limitations affect the maximum allowable grounded length while running anchors. Longer grounded length increases the friction loads with the seabed and can prevent the anchor from being properly set.
- Anchor handling vessels will have limited power to drag the mooring lines across the seabed (in shallow water).

MOORING LINE PROPERTIES

Chain (New)

An accurate representation of the holding capacity or breaking strength of a mooring chain is of the utmost importance to a mooring analysis. This is an area of uncertainty demonstrated by low tension failures that have occurred in the North Sea as well as the high number of failures that occur during anchor placement. This is a problem brought about by the following factors inherent to mooring chains:

- Lack of Redundancy
- Strength Variability

The lack of redundancy is illustrated by the adage the chain is only as strong as the weakest link. The impact of strength variation is shown in a probability study[11] that calculated the most likely breaking strength of a mooring line was significantly below the listed catalog breaking strength (CBS). The example chosen was for a 4000 feet section of 3" ORQ (1044 kip CBS) chain containing approximately 4000 links. Each individual link was assumed to have an average breaking strength of 1200 kips (15% above CBS)

* Anchor uplift is prevented by having sufficient length such that the line is tangential to the sea floor during maximum loadings.

and a standard deviation of 90 kips (7.5 %).* The analysis predicted a probable breaking strength of 886 kips for the entire line, which was 15 percent below the rated breaking strength. Clearly, the results are highly dependent on the average strength and standard deviation chosen, but the example brings out the importance of knowing all the parameters that govern the strength of a mooring line. The lack of data[5] in this regard makes accurately predicting mooring line break strength exceedingly difficult.

An excellent example of this problem concerned the early use of K4 chain which was found to have very high variations in the strength of individual links. Use of this chain resulted in an abnormally high percentage of failures. Chain manufacturers claim that these early problems have now been resolved, but there is still a significant quantity of old K4 chain in service.

Strength variability is a function of a working quality control program. Overall, the chain manufacturing industry has made significant improvements in implementing quality control measures, but achieving reliable manufacturing controls is a difficult process. The importance of a quality program is shown by a survey of 81 failures in the North Sea where half of the chains were seriously flawed during manufacturing.[12] Problems such as overheating material, brittlement due to wrong welding or heat treatment, and hydrogen embrittlement were cited as contributing to the failures. The limited amount of testing does not seem to ensure material flaws are detected.

Chain (Used)

The breaking strength of used chain is even more difficult to predict. Chain endures some degree of strength reduction over its useful life through handling, fatigue, wear, corrosion, etc., but the magnitude of degradation is generally unknown. Inspection procedures have been well established[13] and done routinely for MODUs at intervals from 1 to 3 years; however, these procedures do not indicate the strength after inspection. Even with current procedures, a proper inspection is difficult to conduct and extremely time consuming. Experience shows that standards are rarely followed rigorously and often limited to a visual inspection focused on finding loose studs.[14] As an example, one semi-submersible suffered a chain failure while running anchors at the first location after the chain had undergone a throughout inspection by a reputable organization.

* The limited number of chain tests from various sources contained in Noble Denton's database indicates a standard deviation of 5 % as typical; however, many of these tests discarded results that fell below CBS, and thus are suspect.

While fatigue of chain has not proved to be a problem in the past, perhaps because chains have generally failed due to manufacturing defects at well below their predicted fatigue lives, recent tests[15] suggest that the fatigue characteristics of K4 chain may be much worse than had been previously predicted.

Connectors

Sections of chain are coupled together with connecting links such as Kenter and Baldt links. Because of their complexity, they are more difficult to manufacture than the standard link. Testing has shown that their break strength is unreliable with many failures occurring below their rated strength,[16] and a low fatigue life is commonly cited.[12,17] These uncertainties have resulted in chain specifications restricting the number of connecting links in each mooring line.[18] In contrast, a survey of failures has found their actual performance is at least as good as the chain itself,[5] even if fatigue lives are lower.

Wire

The breaking strength of wire ropes is generally established by testing a specimen length to destruction under tensile load. Some tests to destruction indicate that the ropes have a mean break strength which is about 15 percent higher than specification, with a standard deviation of about 2.5 percent of specified value, thus illustrating that the probability of cable strength falling below the specified minimum is very small ($<10^{-6}$).

It is worthwhile noting that the manufacture of wire ropes involves considerable deformation of the wires as they are bent and drawn through a die to form strands and subsequently ropes. Manufacturing imperfections can be highlighted during this process and faults rectified prior to dispatch.

The disadvantage associated with wire rope is that it's more susceptible than chain to operational wear, corrosion and degradation, which may lead to unexpected failure. When a wire is subjected to a high axial load on MODUs, the bending stiffness of the rope is increased. When it is subsequently bent around a fairlead, the resulting internal damage can be significant. The reliability of used wire rope was the subject of a Joint Industry Study[19] lead by Noble Denton. A conclusion drawn by one reputable drilling contractor was that they should change out the wire in their chain/wire mooring systems every 3 to 5 years. During a storm in the North Sea, it was particularly those wires which had not been changed out that failed, even though they were not the most highly loaded lines.

WATER DEPTH EFFECT

Shallow Water

Semi-submersibles capable of operating in deep water can create an expectation that the they can operate in calmer shallow water with ease. Shallow water operations, however, alter many of the characteristic forces acting on the mooring system and can create larger mooring line tensions than deep water operations.

Mooring System Stiffness In shallow water, as the mooring system stiffness increases, the dynamic vessel motions become a larger force contributor resulting in higher line tensions. The same size motions will cause higher line loads. This effect is more pronounced for vessels that are sensitive to low frequency motions such as a large 4th generation semi-submersibles.

Vessel Motions Caution should be taken when using motion response characteristics (RAOs) of a vessel in shallow water. The effects of shallow water on vessel motions are felt when the depth of water is less than about four times the draft. The changes are caused by the altered wave patterns and hydrodynamic properties resulting from the nearness of the ocean bottom. Many vessel RAOs are based on deep water model tests and may yield non-conservative results for shallow water operations. Also in extremely shallow water, the stiffness of the mooring system can effect the RAOs and should be accounted for in any test or computer simulations.

Deep Water

Mooring line dynamics generate significant loadings in deep water.* A quasi-static analysis can significantly underestimate the magnitude of the dynamic tensions, and this discrepancy increases with water depth.[20] As water depth increases, the magnitude of low frequency motions also increase. At extreme water depths, low frequency motions can be the limiting factor in a mooring analysis.

WINCH POLICY

While many mooring analyses for semi-submersibles in the North Sea are based on the assumption that a fully optimized winch policy is used, in reality, it is rarely employed by the crews. In order to utilize active winching, the crew must remove the chain stoppers and release the brakes during the height of the storm. Many winch and brake systems are not designed to handle this amount of load, and thus, the reluctance on the

* Water depths of greater than 1500 feet are generally considered deep water.

part of the crews. There is some discussion[5] on optimizing the loads in the early part of the storm when tensions are low, but this makes the system extremely sensitive to weather direction, and any change in the direction may increase the loads.

WIND AVERAGING POLICY

When computing a mean offset, a constant wind speed with a specified averaging period is used. Several different standards exist when selecting an averaging period; API is 1 minute and DNV is 10 minute. Generally, a 10 minute is approximately 18 percent less than the 1 minute and since wind force varies with wind speed squared, the difference between the resulting wind forces is even larger. Since the sway natural period of a semi-submersible will normally be between one and two minutes, it would appear unreasonable to use a shorter averaging period. Additionally, for much shorter averaging periods, the area of effect of the wind "gust" is not sufficiently large to encompass the entire unit.

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Appendix E - INDEX TO RELATED ARTICLES

Overall Review

"API Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures," Draft, May 1994

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Appendix F - COMPARISON OF API AND DNV MOORING PROCEDURES

Significant differences exist between the two most widely used MODU mooring analysis procedures. Some of the major differences are itemized below.

Environmental Criteria

- Design Return Period

API
⇒ 5 years when operating in isolated areas ⇒ 10 years when operating adjacent to other structures ⇒ 1 year for tropical revovling storm (TRS) areas
DNV
The more severe of: ⇒ 100 year Wave + 100 year Wind + 10 year current or ⇒ 100 year Wave + 10 year Wind + 100 year current

- Wind Averaging Period

API	DNV
⇒ 1 min. steady component or ⇒ 1 hour steady component + LF dynamic component	⇒ 10 min. steady component

Analysis Criteria

- **Low Frequency Motions**

API	DNV
⇒ Required in all analyzes	⇒ Semis: Required in water depth of greater than 1500 feet. ⇒ Tankers: Always required.

- **Dynamic Motion Calculation**

API	DNV
Dynamic Offset equals greater of 1) $WF_{max} + LF_{sig}$ 2) $WF_{sig} + LF_{max}$	Dynamic Offset equals $\sqrt{WF_{max}^2 + LF_{max}^2}$ Note: Yields results approx. 10-15% lower than API formula

- **Safety Factors (Survival)**

	Quasi-Static			Dynamic		
	API	**DNV Near***	**DNV Far**	**API**	**DNV Near***	**DNV Far**
Intact	2.00	2.00	1.80	1.67	1.65	1.50
Damaged	1.43**	1.40	1.25	1.25**	1.25	1.10
Transient	1.18**	1.10	1.10	1.05**	1.10	1.00

* When operating near a fixed installation. Near is defined as when clearance between a moored unit and another structures is less than the length of the moored unit.

** API requires damage and transient analysis only when moored adjacent to another structure.

- **Safety Factors (Operational)**

	Quasi-Static			Dynamic		
	API	DNV Near*	DNV Far	API	DNV Near*	DNV Far
Intact	2.00	3.00	2.70	1.67	2.50	2.30
Damaged	1.43**	2.00	1.80	1.25**	1.65	1.50
Transient	1.18**	1.40	1.40	1.05**	1.20	1.20

* When operating near a fixed installation. Near is defined as when clearance between a moored unit and another structures is less than the length of the moored unit.

** API requires damage and transient analysis only when moored adjacent to another structure.

- **Anchor Uplift**

API	DNV
Uplift check at offset of greater of the following: 1) Mean + WFmax + LFsig 2) Mean + WFsig + LFmax Must be met for: • Intact • Damaged (if required) • Transient (if required)	Uplift check for following cases: • Intact for the greater of Mean + WFsig or Mean + LF sig • Transient with mean forces only

The importance various assumptions and methods such as those listed previously can have on computed line tensions is illustrated in the following table. The initial tension was computed using a quasi-static mooring analysis using API RP methods and was normalized to 1000 to allow for easier comparison.

Table F.1 Mooring Assumptions Effect On Computed Line Tensions

Condition	Tension
• Initial Tension (ISSC Spectrum, All Lines Slack, Wave Period 11 sec)	1000
• Use Jonswap Sea Spectrum	912
• Use Short Crested Sea Assumption (ref.: DNV POSMOOR)	835
• Assume Low Frequency Damping Equals 20% Of Critical (Initial Case Uses 10%)	618
• Use Wind Dynamics Versus Quasi-Static Wind	609
• Use DNV Method Of Combining Dynamic Motions	542
• Neglect Low Frequency Motions	454
• Use Actual Chain Stretch Coefficients	442

Appendix G - POST-INCIDENT MOORING ANALYSIS FOR HURRICANE ANDREW

ZAPATA SARATOGA

A mooring review has been conducted to attempt to determine the performance of the "*ZAPATA SARATOGA*" in Hurricane Andrew. A brief explanation of methodology used in this analysis is as follows. A set of quasi-static analyses were performed in accordance with the draft API Stationkeeping RP dated May, 1994. Vessel properties and force coefficients were taken from Noble Denton's library. RAOs and low frequency motions were scaled from tables in the API RP. Weather used was obtained from a hindcast performed by Oceanweather, Inc.. Since mooring line lengths and pretensions were unknown, three different scenarios were evaluated with the results listed in the table below. In all cases, a collinear environment from the quarter provided the most severe line tensions. Results are contained in Table G.1.

For a comparison, the 2600 feet case was evaluated to the 5 and 10 year criteria found in Table G.2. A standard thumb rule for operating in 850 feet of water depth recommends the deployment of line scope equal to 3 times the water depth (2600 feet). For this reason, as well as it satisfies the API 5 year criteria, the 2600 feet case seems to be a reasonable assumption as to a possible actual condition. Note, this line scope produces the highest tension level of the three evaluated. A scope of 4000 feet reduces the line tensions by over 25 percent.

Had the "*ZAPATA SARATOGA*" deployed 2600 feet of line scope, the actual performance during Hurricane Andrew seems to suggest that this amount was inadequate. Also, the method used to determine the amount of scope to deploy would seem to be inadequate. This assumes that there were no material defects causing the line to fail prematurely. In Table G.1, the 2600 feet case satisfied the minimum 5 year criteria for isolated operation. When evaluated against either a 5 year return period combined with a one-line damage criteria or a straight 10 year return period, the 2600 feet scope is shown to be insufficient. If either of these criteria were used when conducting the initial on-site analysis, the "*ZAPATA SARATOGA*" would have been required to use greater than 2600 feet line scope.

ZANE BARNES

The *"ZANE BARNES"* was stacked in 167 feet water depth with approximately 1200 feet of line scope during Hurricane Andrew. A more accurate analysis than used for the *"ZAPATA SARATOGA"* was allowed since a detailed motion analysis was available. The results of the mooring analyzes using estimated conditions during Andrew and two standard return periods are contained in Table G.3.

While the *"ZANE BARNES"* was able to demonstrate adequate safety factors to the 99.9% non-exceedence criteria from API 2P, this line scope was not sufficient to enable the semi-submersible to withstand Hurricane Andrew force conditions. If the MODU is evaluated to the new API Stationkeeping RP's 5 year criteria, the system deployed is shown to be inadequate. In order to meet this criteria, the *"ZANE BARNES"* would be required to use deploy more line or moor in deeper water. While meeting the 5 year criteria does not guarantee it would have survived intact, it does raise the probability of survival from the condition moored in Andrew.

OCEAN NEW ERA

Like the *"ZAPATA SARATOGA"*, the condition of the *"OCEAN NEW ERA's"* mooring system prior to Andrew was unknown. A maximum line length of 3300 feet was assumed. Assuming this was the length deployed, a quasi-static analysis to the API RP was carried out. Results are shown in Table G.4. Calculated line tensions levels are slightly greater than the mooring line CBS.

We understand that at least one of the Ocean MODUs dragged anchors up to 800 feet and in view of the high loading for the "Ocean New Era" and its proximity to the path, it seems likely this may be the candidate. If so, this slippage of the anchors may explain why the lines did not fail. This case highlights the potential benefit that can be gained by a small amount of anchor drag during survival conditions.

OCEAN VOYAGER

The *"OCEAN VOYAGER"* was located on the far western side of the storm and received the less impact of the storm than the *"OCEAN NEW ERA"*. The *"OCEAN VOYAGER"* received no reported damage but is a shown for comparison. In Table G.5, two cases were analyzed to determine the impact of line length.

All the computed line tensions for the *"OCEAN VOYAGER"* were more than 40 percent lower than the *"OCEAN NEW ERA*'s". Thus, it thus seems reasonable the *"OCEAN VOYAGER"* escaped Hurricane Andrew without harm.

Table G.1 "ZAPATA SARATOGA" Mooring Analysis for Hurricane Andrew

Weather Mississippi Canyon Block 705 during Andrew			
Wind (1 min.)	98 kts		
Significant Wave Height	37 ft.		
Peak Wave Period	13.0 sec		
Current, Surface	1.8 kts		
Chain Length Wire Length	2500 ft 3500 ft	2500 ft 1500 ft	2500 ft 100 ft
Pretension	100 kips	100 kips	100 kips
Mean Force	848.2 kips	848.2 kips	848.2 kips
Mean Offset	84.8 ft	109.1 ft	244.0 ft
Mean Tension	346.2 kips	444.1 kips	479.4 kips
Wave Motion, Sig	8.6 ft	8.6 ft	8.6 ft
Wave Motion, Max	16.0 ft	16.0 ft	16.0 ft
LF Motion, Sig	3.4 ft	3.8 ft	3.5 ft
LF Motion, Max	5.5 ft	6.1 ft	5.4 ft
Total Dynamic Offset	19.6 ft	19.8 ft	19.5 ft
Total Offset	104.2 ft	129.0 ft	263.6 ft
Maximum Tension	**600.4 kips**	**566.1 kips**	**766.9 kips**
Safety Factor	**1.16**	**1.23**	**0.91**
Minimum Grounded Length	952 ft	0 ft	0 ft
Maximum Anchor Load	520.6 kips	535.8 kips	713.3 kips
Anchor Uplift Force	0 kips	28.5 kips	153.1 kips

Table G.2 "ZAPATA SARATOGA" Mooring Analysis to API Criteria

Weather	**GOM 5 year**		**GOM 10 year**
Wind (1 min.)	63 kts		72 kts
Significant Wave Height	27 ft.		30 ft.
Peak Wave Period	13.0 sec		13.0 sec
Current, Surface	1.4 kts		1.8 kts
	Intact	**Damage**	**Intact**
Pretension	100 kips	100 kips	100 kips
Mean Force	386.4 kips	386.4 kips	487.8 kips
Mean Offset	183.1 ft	263.4 ft	209.9 ft
Mean Tension	244.6 kips	374.9 ft	205.8 kips
Wave Motion, Sig	5.8 ft	5.8 ft	6.9 ft
Wave Motion, Max	10.9 ft	10.9 ft	12.8 ft
LF Motion, Sig	6.2 ft	9.7 ft	12.7 ft
LF Motion, Max	9.3 ft	13.8 ft	19.3 ft
Total Dynamic Offset	17.1 ft	20.6 ft	26.2 ft
Total Offset	200.3 ft	283.5 ft	231.9 ft
Maximum Tension	**278.9 kips**	**545.2 kips**	**387.5 kips**
Safety Factor	**2.49**	**1.28**	**1.79**
Minimum Safety Factor	2.00	1.43	2.00
Minimum Grounded Length	52 ft	0 ft	0 ft
Maximum Anchor Load	221.3 kips	492.2 kips	334.7 kips
Anchor Uplift Force	0 kips	82.3 kips	31.6 kips

Table G.3 "ZANE BARNES" Mooring Analysis

Weather	**Hurr. Andrew**	**GOM 99.9%**	**GOM 5 year**
Wind (1 min.)	104 kts	38 kts	63 kts
Significant Wave Height	30 ft.	13.0 ft.	27 ft.
Peak Wave Period	11.0 sec	9.0 sec	13.0 sec
Current, Surface	2.0 kts	1.1 kts	1.4 kts
Pretension	50 kips	100 kips	100 kips
Mean Force	1771.6 kips	241.4 kips	714.5 kips
Mean Offset	47.4 ft	12.3 ft	24.5 ft
Mean Tension	740.5 kips	177.4 kips	413.4 kips
Wave Motion, Sig	4.8 ft	1.0 ft	5.4 ft
Wave Motion, Max	9.4 ft	1.9 ft	10.1 ft
LF Motion, Sig	3.2 ft	8.3 ft	4.8 ft
LF Motion, Max	5.4 ft	13.1 ft	7.6 ft
Total Dynamic Offset	12.6 ft	14.1 ft	14.8 ft
Total Offset	60.0 ft	26.4 ft	39.3 ft
Maximum Tension	**2387 kips**	**461.8 kips**	**1455 kips**
Safety Factor	**0.67**	**3.72**	**1.18**
Minimum Grounded Length	0 ft	44 ft	0 ft
Maximum Anchor Load	1942 kips	435 kips	1436 kips
Anchor Uplift Force	200 kips	0 kips	125 kips

Table G.4 "OCEAN NEW ERA" Mooring Analysis

Weather Grand Isle Block 107 during Andrew	
Wind (1 min.)	104 kts
Significant Wave Height	30 ft.
Peak Wave Period	11.0 sec
Current, Surface	2.0 kts
Pretension	100 kips
Mean Force	1160 kips
Mean Offset	56.1 ft
Mean Tension	596 kips
Wave Motion, Sig	9.0 ft
Wave Motion, Max	16.7 ft
LF Motion, Sig	2.3 ft
LF Motion, Max	3.9 ft
Total Dynamic Offset	19.1 ft
Total Offset	75.2 ft
Maximum Tension	**954.3 kips**
Safety Factor	**0.93**
Minimum Grounded Length	600 ft
Maximum Anchor Load	899 kips
Anchor Uplift Force	0 kips

Table G.5 "OCEAN VOYAGER" Mooring Analysis

Weather Ship Shoal Block 231 during Andrew		
Wind (1 min.)	107 kts	
Significant Wave Height.	33 ft	
Peak Wave Period	11.0 sec	
Current, Surface	1.8 kts	
Chain Length	3000 ft	2500 ft
Pretension	100 kips	100 kips
Mean Force	1066.4 kips	1066.4 kips
Mean Offset	29.4 ft	28.4 ft
Mean Tension	448.9 kips	465.8 kips
Wave Motion, Sig	4.2 ft	4.2 ft
Wave Motion, Max	7.8 ft	7.8 ft
LF Motion, Sig	1.7 ft	1.7 ft
LF Motion, Max	2.8 ft	2.8 ft
Total Dynamic Offset	9.5 ft	9.5 ft
Total Offset	39.0 ft	37.9 ft
Maximum Tension	**683.3 kips**	**742.5 kips**
Safety Factor	**1.53**	**1.40**
Minimum Grounded Length	1421 ft	868 ft
Maximum Anchor Load	562 kips	664 kips
Anchor Uplift Force	0 kips	0 kips

Appendix H - INCIDENT INVESTIGATIONS

Currently, all marine accidents in US Waters, such as severe mooring failures, are required to be reported to the nearest US Coast Guard Marine Safety Office as directed by the Code of Federal Regulations (CFR Title 46, Subpart 4.05 & 4.07). It is then the Coast Guard's responsibility to conduct an investigation as to determine the cause of the accident. As part of this tasking, a survey of past mooring incidents was conducted to determine the breath of information available on mooring failures. Copies of the U.S. Coast Guard investigations for the Hurricane Andrew mooring failures of the *"ZANE BARNES"*, *"ZAPATA SARATOGA"*, and *"TREASURE 75"* are included in this appendix. Submersible incidents in Andrew such as the *"PORTAL 201"* and *"PORTAL 202"* were not documented by the Coast Guard. Nor were any investigation found on past mooring failures such as *"ZAPATA YORKTOWN's"* failure in Hurricane Elena, 1985.

The investigations conducted after Hurricane Andrew are very cursory in nature. The conclusions they draw are simply; that failures occurred due to storm overloading. The purpose of any marine investigation should be to gather information as to improve current practices and decrease the likelihood of future similar incidents from occurring. To further this end, it is recommended that incidents are investigated in detail and a recommended list of information to be gathered in future investigations is as follows:

1. General Information
   - a) Name of MODU
   - b) Type of MODU
   - c) Brief description of incident
   - d) Date
   - e) Location (Lat/Long)
   - f) Water depth
   - g) Personnel involved and qualifications

2. MODU Data (to be gathered from Operations Manual or Owner)
    a) General MODU Particulars
        i) Length
        ii) Width
        iii) Draft
        iv) Displacement
        v) Daily Stability Calculation
    b) Mooring System
        i) Size of chain and/or wire
        ii) Type of chain and/or wire
        iii) Breaking load of lines
        iv) Manufacture data
        v) Anchor Type
        vi) Date of manufacturer
        vii) Last inspection date (obtain copy if available)
    c) Operational Limits
        i) Maximum environment for survival and operational conditions
        ii) Basis for design conditions
        iii) Criteria for disconnecting of marine riser
3. Mooring Pattern Deployed
    a) Individual line lengths and pretension levels
    b) Anchor positions
    c) Anchor test load
    d) Heading
    e) Special considerations (e.g., subsea equipment, adjacent platform)
    f) Site specific mooring analysis (if available)

4. Condition Abandoned (if applicable)
    a) Line tensions when abandon
    b) Amount of line paid out
    c) When remanned or recovered
    d) If vessel was adrift, location when discovered
5. Chronology surrounding casualty (if manned)
    a) Weather Conditions
    b) Drilling condition
    c) Vessel motions (pitch, heave, roll)
    d) Mooring line tensions (method of recording)
    e) Winching actions
    f) Sequence of events
6. Details Of Failure
    a) Position of mooring failure (fairlead, mid-section, etc.)
    b) Type of component
    c) Cause of failure (material defect, fatigue, etc.)
    d) Recover failed component, if possible
    e) Any related damage (damage to riser or other structures)
    f) Any potential damage avoided (near miss)
    g) Did anchors drag and, if so, how much

MCIR MARINE CASUALTY INVESTIGATION REPORT 28JUL94

CASE NUMBER../ MC93003594 INV INIT/ IJV PORT/ NEWMS LAST UPDATE/ 29MAR93
CASUALTY TYPE: VESSEL/ X PERSONNEL/ FACILITY/ POLLUTION/ MARPOL/
INCIDENT DATE/ 27AUG92 TIME/ 1517 KNOWN/ ESTIMATED/ X REF CASE/
NOTIFY DATE../ 02MAR93 TIME/ 1517 REPORTER TYPE/ RESP PARTY
SUBJECT....../ TREASURE 75 LOCAL FILE REFERENCE/
LOCATION...../ GULF OF MEXICO LOCAL CODE/
INCIDENT STATUS: VERIFIED/ NOT VERIFIED/ VERIFIED, NOT REPORTABLE/ X
NOTIFY/ ACTION: CTF/ X RETURN/ (TO IAPR)

--- VALIDATION AND ENDORSEMENT ---

	END/FWD	END/CLS	RETURN	USER-ID	NAME	DATE
INVESTIGATOR:	X			IJV	LTJG IVAN J. VIKIN	28MAR93
UNIT COMMAND:		X		LTAT	LTJG AMY TAYLOR	29MAR93
DIST REQ? :						
HQ REQ? :						

--- GENERAL INFORMATION ---

CITY/ ST/ WATERBODY/ GULF OF MEXICO 12-200 MILES
RIVER MILE/ . LATITUDE/ N 28-55.0 LONGITUDE/ W 90-35.0
CAS SUMMARY:TYPE/ STRUCT FAIL CLASS/ NONE
POSSIBLE DRUG INVOLVEMENT?/ N PUBLIC VESSEL/ BOATING/
DEATHS/ MISSING/ INJURED/ TOTAL DAMAGE/ 10000
ENV IMPACT: MODE/ SEVERITY CATEGORY/ MATERIAL CATEGORY/
OSC/ EPA REGION/ CLEANUP REQ?/
RESPONSE BY NSF?/ NSF TIME TO RESPOND/ HOURS
NOTIFICATION FROM NRC?/ NRC CASE/

--- INCIDENT BRIEF ---

27AUG92: THE MODU TREASURE 75, D574670, (NEW NAME: FPS LAFITT PINCAY), AS A RESULT OF HURRICANE ANDREW, DRIFTED FROM ITS ANCHORAGE AT SOUTH PELTO BLOCK 7 TO A LOCATION THREE MILES WEST. ALL FOUR ANCHORS ONBOARD THE TREASURE 75 WERE DEPLOYED. RESULTING DAMAGE TO THE MODU WAS MINIMAL. DURING THE HURRICANE, THE MODU DRAGGED ANCHOR ACROSS A TEXACO PIPLINE LOCATED IN SOUTH PELTO BLOCK 8 RESULTING IN A 2000 BBL SPILL. SEE POLLUTION CASE MV92013018 FOR MORE INFO.

--- ACTIONS REPORTED ---

SEL	CASE SUPPLEMENTS		SEL	EVENT SUPPLEMENTS	
1	WITNESS LIST.........(IAWL)/		12	COLLISION OR GROUNDING.(MCCG)/	0
2	COMDT RECOMMENDATION.(MCCR)/		13	EQUIP FAILURE..........(MCDR)/	0
3	CASUALTY DETAILS.....(MCDD)/		14	FLOOD,CAPSIZE,SINKING..(MCFC)/	0
4	NARRATIVE SUPPLEMENT.(MCNS)/		15	FIRE,EXPLOSION.........(MCFE)/	0
5	PERS ACTION RECOMMEND(MCPA)/	0	16	HUMAN FACTORS SUPP.....(MCHF)/	0
6	POLLUTANT DETAILS....(MCPD)/	0	17	HAZ MAT INVOLVEMENT....(MCHM)/	0
7	PERSONNEL INVOLVEMENT(MCPI)/	0	18	LIFESAVING SUPPLEMENT..(MCLS)/	0
8	SMI SUPPLEMENT.......(MCSI)/	0	19	PERSONNEL CASUALTY.....(MCPC)/	0
9	TOWING SUPPLEMENT....(MCTS)/	0	20	STRUCTURAL FAILURE.....(MCSF)/	0
10	SUBJECT SUPPLEMENT...(MCSS)/				
11	WEATHER FACTORS......(MCWX)/				

VESSELS INVOLVED/ 1

VIN	NAME	FLAG	SERVICE	-SUPPLEMENTS- P D	F R	P A	P I	S I	TOW REF	DMG
D574670	FPS LAFITT PINCAY	US	MODU							SEA

FACILITIES INVOLVED/ 0

--- INVESTIGATION RESOURCES UTILIZED ---

ACTIVITY CATEGORY	TOTAL HOURS	------- RESOURCE CATEGORY ------- REGULAR	RESERVE	CIVILIAN	OTHER

UNIT/ NEWMS

MCIR MARINE CASUALTY INVESTIGATION REPORT 28JUL94

CASE NUMBER../ MC92015651 INV INIT/ IJV PORT/ NEWMS LAST UPDATE/ 26JAN93
CASUALTY TYPE: VESSEL/ X PERSONNEL/ FACILITY/ POLLUTION/ MARPOL/
INCIDENT DATE/ 25AUG92 TIME/ KNOWN/ X ESTIMATED/ REF CASE/
NOTIFY DATE../ 17SEP92 TIME/ 1200 REPORTER TYPE/ RESP PARTY
SUBJECT....../ ZAPATA SARATOGA LOCAL FILE REFERENCE/
LOCATION...../ GULF OF MEXICO LOCAL CODE/
INCIDENT STATUS: VERIFIED/ X NOT VERIFIED/ VERIFIED, NOT REPORTABLE/
NOTIFY/ ACTION: CTF/ RETURN/ (TO IAPR)

--- VALIDATION AND ENDORSEMENT ---

	END/FWD	END/CLS	RETURN	USER-ID	NAME	DATE
INVESTIGATOR:	X			IJV	LTJG IVAN J. VIKIN	11JAN93
UNIT COMMAND:		X		LTAT	LTJG AMY TAYLOR	26JAN93
DIST REQ? :						
HQ REQ? :						

--- GENERAL INFORMATION ---

CITY/ ST/ WATERBODY/ GULF OF MEXICO COASTAL
RIVER MILE/ . LATITUDE/ N 28-15.0 LONGITUDE/ W 89-55.0
CAS SUMMARY:TYPE/ FLOODING CLASS/ MAJOR
POSSIBLE DRUG INVOLVEMENT?/ Y PUBLIC VESSEL/ BOATING/
DEATHS/ MISSING/ INJURED/ TOTAL DAMAGE/ 5000000
ENV IMPACT: MODE/ SEVERITY CATEGORY/ MATERIAL CATEGORY/
OSC/ EPA REGION/ CLEANUP REQ?/
RESPONSE BY NSF?/ NSF TIME TO RESPOND/ HOURS
NOTIFICATION FROM NRC?/ NRC CASE/

--- INCIDENT BRIEF ---

VESSEL DAMAGED DURING HURRICANE ANDREW.
NO INJURIES,
NO POLLUTION,
NO DEATHS.

--- ACTIONS REPORTED ---

SEL	CASE SUPPLEMENTS		SEL	EVENT SUPPLEMENTS	
1	WITNESS LIST.........(IAWL)/		12	COLLISION OR GROUNDING.(MCCG)/	0
2	COMDT RECOMMENDATION.(MCCR)/		13	EQUIP FAILURE..........(MCDR)/	0
3	CASUALTY DETAILS.....(MCDD)/	X	14	FLOOD,CAPSIZE,SINKING..(MCFC)/	1
4	NARRATIVE SUPPLEMENT.(MCNS)/		15	FIRE,EXPLOSION.........(MCFE)/	0
5	PERS ACTION RECOMMEND(MCPA)/	0	16	HUMAN FACTORS SUPP.....(MCHF)/	0
6	POLLUTANT DETAILS....(MCPD)/	0	17	HAZ MAT INVOLVEMENT....(MCHM)/	0
7	PERSONNEL INVOLVEMENT(MCPI)/	0	18	LIFESAVING SUPPLEMENT..(MCLS)/	0
8	SMI SUPPLEMENT.......(MCSI)/	0	19	PERSONNEL CASUALTY.....(MCPC)/	0
9	TOWING SUPPLEMENT....(MCTS)/	0	20	STRUCTURAL FAILURE.....(MCSF)/	0
10	SUBJECT SUPPLEMENT...(MCSS)/				
11	WEATHER FACTORS......(MCWX)/	X			

VESSELS INVOLVED/ 1

VIN	NAME	FLAG	SERVICE	-SUPPLEMENTS- P D	F R	P A	P I	S I	TOW REF	DMG
CG030214	ZAPATA SARATOGA	US	MODU							SEA

FACILITIES INVOLVED/ 0

--- INVESTIGATION RESOURCES UTILIZED ---

ACTIVITY CATEGORY	TOTAL HOURS	------- RESOURCE CATEGORY ------- REGULAR	RESERVE	CIVILIAN	OTHER

UNIT/ NEWMS

CASE NUMBER/ MC92015651 ARE ALL SUPPLEMENTS COMPLETED?/ Y

--- SUBJECT REFERENCE MAP ---

REF	VIN	NAME	SERV	OPERATION	CONTROL STATUS
1.	CG030214	ZAPATA SARATOGA	MODU	HLD	ANCHORED

COMMENT/

--- CASUALTY PROLOGUE ---

HURRICANE DAMAGED RIG.

--- CASUALTY EVENT SEQUENCE ---

EV	SUBJ'S	EVENT TYPE	EVENT CLASS	EVENT STATE	CAUSAL EVENTS
1	1	FLOODING	UNCONTROLLED	MULTIPLE AREAS	

CAT	SUBJ	CAUSAL/ENABLING FACTORS CLASS	SUBCLASS	STATE	PARTY	CAUSAL EVENT	SUP (X)
WX	1	WEATHER COND	WAVES	HURRICANE	PIC		

MCWX MARINE CASUALTY WEATHER FACTORS 28JUL94

CASE/ MC92015651 SUBJECT/ ZAPATA SARATOGA

--- PRE CASUALTY WEATHER CONDITIONS ---

TIME/ WEATHER/ RAIN VISIBILITY: CONDITION/ POOR DISTANCE/
EXPLANATION OF OTHER/

AIR TEMP/ F WIND: SPEED/ 100 DIRECTION/

SEA OR RIVER: WAVE HEIGHT../ 30 DIRECTION/
SWELL HEIGHT./ DIRECTION/
CURRENT SPEED/ DIRECTION/
RIVER STAGE../
TIDE........./

--- POST CASUALTY WEATHER CONDITIONS ---

SIG	ELEMENT		TREND
	WEATHER............./		
	VISIBILITY CONDITION/		
	VISIBILITY DISTANCE./		
	AIR TEMP............/		
X	WIND SPEED........../	100	INCREASING
X	WAVE HEIGHT........./	30	INCREASING
	SWELL HEIGHT......../		
	CURRENT SPEED......./		
	WIND DIRECTION....../		
	WAVE DIRECTION....../		
	SWELL DIRECTION...../		
	CURRENT DIRECTION.../		
	RIVER STAGE........./		
	TIDE................/		

MCFC MARINE CASUALTY FLOOD, CAPSIZE, SINKING SUPPLEMENT 28JUL94

CASE NUMBER...../ MC92015651 DELETE/
1. VESSEL NAME/ ZAPATA SARATOGA VIN/ CG030214

SIG	EVENT	TYPE	CLASS	STATE
X	1	FLOODING	UNCONTROLLED	MULTIPLE AREAS

WAS VESSEL IN AN INTACT OR DAMAGED CONDITION?/ INTACT
CAUSE OF FLOODING............................./ HURRICANE
SPECIAL CIRCUMSTANCES../

WAS THE VESSEL REQUIRED TO MEET INTACT STABILITY CRITERIA?....../
DID THE VESSEL MEET ITS INTACT STABILITY CRITERIA?............../
WAS THE VESSEL REQUIRED TO MEET DAMAGED STABILITY CRITERIA?...../
DID THE VESSEL MEET ITS DAMAGED STABILITY CRITERIA?............./
WERE THERE ANY SPECIAL STABILITY INSTRUCTIONS/INFO AVAILABLE?.../
WERE THE SPECIAL STABILITY INSTRUCTION/INFO FOLLOWED?.........../
DID THE OPERATING PERSONNEL KNOW HOW TO USE THE STABILITY INFO?./

NUMBER OF COMPARTMENTS FLOODED?/ 0
USE OF THE COMPARTMENTS THAT FLOODED:

TIME TO SINK: HOURS/ MINUTES/
MANNER OF SINKING:

DRAFTS:	FWD		AFT	
PRE-CASUALTY...../		(UNITS)		(UNITS)
POST-CASUALTY..../		(UNITS)		(UNITS)

--- DESCRIPTION ---

THE MOORING SYSTEM, RADIO ANTENNAS, RADAR ANTENNA AND NUMEROUS ELECTRIC MOTORS WERE DAMAGED FROM THE HURRICANE DRIVEN WIND AND WAVES. DRILL FLOOR WAS FLOODED DUE TO HIGH SEAS AND WINDS WHICH CAUSED ADDITIONAL DAMAGE TO THE EXTERIOR LIGHTING SYSTEM. VESSEL IS STILL SEA WORTHY.

MCIR MARINE CASUALTY INVESTIGATION REPORT 21APR93

CASE NUMBER../ MC92015048 INV INIT/ ITO PORT/ MORMS LAST UPDATE/ 21APR93
CASUALTY TYPE: VESSEL/ X PERSONNEL/ FACILITY/ POLLUTION/
INCIDENT DATE/ 25AUG92 TIME/ 2118 KNOWN/ ESTIMATED/ X REF CASE/
NOTIFY DATE../ 09SEP92 TIME/ 1200 REPORTER TYPE/ COMM. SOURCE
SUBJECT....../ MODU ZANE BARNES: GROUNDING LOCAL FILE REFERENCE/ 32/162/92
LOCATION...../ SOUTH TIMBALIER 32 LOCAL CODE/
INCIDENT STATUS: VERIFIED/ X NOT VERIFIED/ VERIFIED, NOT REPORTABLE/
NOTIFY/ ACTION: CTF/ RETURN/ (TO IAPR)

--- VALIDATION AND ENDORSEMENT ---

	END/FWD	END/CLS	RETURN	USER-ID	NAME	DATE
INVESTIGATOR:	X			OFFUTT	LTJG T. OFFUTT	21APR93
UNIT COMMAND:		X		Curley		4/21/93
DIST REQ? N :						
HQ REQ? N :						

--- GENERAL INFORMATION ---

CITY/ MORGAN CITY ST/ LA WATERBODY/ GULF OF MEXICO 12-200 MILES
RIVER MILE/ . LATITUDE/ N 28-41.3 LONGITUDE/ W 90- 2.9
CAS SUMMARY:TYPE/ GROUNDING CLASS/ MAJOR
POSSIBLE DRUG INVOLVEMENT?/ Y PUBLIC VESSEL/ BOATING/
DEATHS/ MISSING/ INJURED/ TOTAL DAMAGE/ 9200000
ENV IMPACT: MODE/ SEVERITY CATEGORY/ MATERIAL CATEGORY/
OSC/ EPA REGION/ RESPONSE REQ?/
RESPONSE BY NSF?/ NSF TIME TO RESPOND/ HOURS
NOTIFICATION FROM NRC?/ NRC CASE/

--- INCIDENT BRIEF ---

AS A RESULT OF IMPEDING HURRICANE ANDREW FORECASTS, THE ABOVE NAMED SEMI-SUBMERSIBLE DRILLING UNIT WAS SECURED AND EVACUATED. VESSEL BROKE LOOSE DURING HURRICANE AND WAS SUBSEQUENTLY GROUNDED IN SOUTH TIMBALIER BLOCK 32. (SEE ENCLOSED COMPANY NARRATIVE).

NOTE: EFFECTIVE 10DEC92, VESSEL'S NAME WAS CHANGED TO "JACK BATES".

--- ACTIONS REPORTED ---

SEL	CASE SUPPLEMENTS		SEL	EVENT SUPPLEMENTS	
1	WITNESS LIST.........(IAWL)/	✓X	12	COLLISION OR GROUNDING.(MCCG)/	1
2	COMDT RECOMMENDATION.(MCCR)/		13	EQUIP FAILURE..........(MCDR)/	0
3	CASUALTY DETAILS.....(MCDD)/	✓X	14	FLOOD,CAPSIZE,SINKING..(MCFC)/	0
4	NARRATIVE SUPPLEMENT.(MCNS)/	✓X	15	FIRE,EXPLOSION.........(MCFE)/	0
5	PERS ACTION RECOMMEND(MCPA)/	0	16	HUMAN FACTORS SUPP.....(MCHF)/	0
6	POLLUTANT DETAILS....(MCPD)/	0	17	HAZ MAT INVOLVEMENT....(MCHM)/	0
7	PERSONNEL INVOLVEMENT(MCPI)/	0	18	LIFESAVING SUPPLEMENT..(MCLS)/	1
8	SMI SUPPLEMENT.......(MCSI)/	0	19	PERSONNEL CASUALTY.....(MCPC)/	0
9	TOWING SUPPLEMENT....(MCTS)/	0	20	STRUCTURAL FAILURE.....(MCSF)/	0
10	SUBJECT SUPPLEMENT...(MCSS)/				
11	WEATHER FACTORS......(MCWX)/	✓X			

VESSELS INVOLVED/ 1

VIN	NAME	FLAG	SERVICE	-SUPPLEMENTS- P D	F R	P A	P I	S I	TOW REF	DMG
D906283	JACK BATES	US	MODU							NSEA

FACILITIES INVOLVED/ 0

102568

--- INVESTIGATION RESOURCES UTILIZED ---

ACTIVITY CATEGORY	TOTAL HOURS	------- RESOURCE CATEGORY ------- REGULAR	RESERVE	CIVILIAN	OTHER

CASE/ MC92015048 SUBJECT/ MODU ZANE BARNES: GROUNDING

--- PRE CASUALTY WEATHER CONDITIONS ---

TIME/ NIGHT WEATHER/ OTHER VISIBILITY: CONDITION/ POOR DISTANCE/
EXPLANATION OF OTHER/ HURRICANE ANDREW

AIR TEMP/ F WIND: SPEED/ DIRECTION/

SEA OR RIVER: WAVE HEIGHT../ DIRECTION/
SWELL HEIGHT./ DIRECTION/
CURRENT SPEED/ DIRECTION/
RIVER STAGE../
TIDE........./

--- POST CASUALTY WEATHER CONDITIONS ---

SIG	ELEMENT	TREND
	WEATHER............../	
	VISIBILITY CONDITION/	
	VISIBILITY DISTANCE./	
	AIR TEMP............/	
	WIND SPEED........../	
	WAVE HEIGHT........./	
	SWELL HEIGHT......../	
	CURRENT SPEED......./	
	WIND DIRECTION....../	
	WAVE DIRECTION....../	
	SWELL DIRECTION...../	
	CURRENT DIRECTION.../	
	RIVER STAGE........./	
	TIDE................/	

CASE NUMBER...../ MC92015048 DELETE/
1. VESSEL NAME/ JACK BATES VIN/ D906283

SIG	EVENT	TYPE	CLASS	STATE
X	2	GROUNDING ACC	OUT OF CHANNEL	NO CONTROL

COURSE/ TRUE SPEED/ KNOTS

--- EXTENT OF DAMAGE ---

IMPACT LOCATION/
DISTANCE FROM FWD PERPENDICULAR TO CENTER OF DAMAGE.../ (FT/IN)
DISTANCE FROM BOTTOM OF KEEL TO LOWER EXTENT OF DAMAGE/ (FT/IN)

DIMENSIONS OF DAMAGE:	TRANSVERSE	LONGITUDINAL	PENETRATION
OVERALL...................../	(FT/IN)	(FT/IN)	(FT/IN)
BELOW BULKHEAD(FREEBOARD) DK/	(FT/IN)	(FT/IN)	(FT/IN)

WAS THIS A DOUBLE BOTTOMED VESSEL?......./ N
WAS THIS A DOUBLE HULLED VESSEL?........./ N
WAS THE INNER HULL BREACHED?............./ Y

PROTECTED AREAS: INVOLVED?/ N DEFORMED?/ N OPENED?/ N NUMBER DAMAGED?/
TYPE OF PROTECTED AREAS INVOLVED:
MULTIPLE AREAS DAMAGE, TOTALING $9,200,000.

--- DESCRIPTION ---

CASE NUMBER...../ MC92015048 DELETE/
1. VESSEL NAME/ JACK BATES VIN/ D906283

EVENT	TYPE	CLASS	STATE
1	ABANDONMENT	PRECAUTIONARY	TOTAL

--- PERSONNEL CASUALTY SUMMARY ---

	CREW/EMP	PAS/VIS	INDUST	OTHER
DEATHS :	0	0	0	0
MIN INJ:	0	0	0	0
SER INJ:	0	0	0	0
MISSING:	0	0	0	0

--- PERSONNEL CASUALTIES ATTRIBUTABLE TO DIRECT EVENT CONSEQUENCES ---

	CREW/EMP	PAS/VIS	INDUST	OTHER
DEATHS :	0	0	0	0
MIN INJ:				
SER INJ:				
MISSING:				

--- PERSONNEL CASUALTIES ATTRIBUTABLE TO ABANDONMENT CONSEQUENCES ---

ABANDONMENT MODE		CREW/EMP	PAS/VIS	INDUST	OTHER
TO LIFEBOAT/LIFERAFT.............................					
	TOTAL PERSONNEL AT RISK:	0	0	0	0
	DEATHS :				
	MIN INJ:				
	SER INJ:				
	MISSING:				
TO WATER WITH PFD/IMMERSION SUIT.................					
	TOTAL PERSONNEL AT RISK:	0	0	0	0
	DEATHS :				
	MIN INJ:				
	SER INJ:				
	MISSING:				
TO WATER WITH NO PERSONAL PROTECTION.............					
	TOTAL PERSONNEL AT RISK:				
REASON: INACCESSIBLE......./	DEATHS :				
INSUFFICIENT TIME../	MIN INJ:				
INADEQUATE WARNING /	SER INJ:				
INSUFFICIENT AMOUNT/	MISSING:				

--- MULTI-PERSON LIFESAVING EQUIPMENT PERFORMANCE ---

	REQ'D	AVAIL	FUNCT	USED	COMMENT
LIFEBOATS	0			0	
RESCUE BOATS	0			0	
INFLATABLE RAFTS	5			0	
FLOATS/BUOYANT APP.	0			0	

--- EFFECTIVENESS OF LIFESAVING EQUIPMENT ---

EVACUATION WAS CONDUCTED WITHOUT THE USE OF VESSEL EQUIPMENT.

CASE NUMBER/ MC92015048 ARE ALL SUPPLEMENTS COMPLETED?/ Y

--- SUBJECT REFERENCE MAP ---

REF	VIN	NAME	SERV	OPERATION	CONTROL STATUS
1.	D906283	JACK BATES	MODU	NOP	ANCHORED

COMMENT/

--- CASUALTY PROLOGUE ---

AS A RESULT OF IMPEDING HURRICANE ANDREW FORECASTS, SUBJECT VESSEL WAS SECURED AND EVACUATED.

--- CASUALTY EVENT SEQUENCE ---

EV	SUBJ'S	EVENT TYPE	EVENT CLASS	EVENT STATE	CAUSAL EVENTS
1	1	ABANDONMENT	PRECAUTIONARY	TOTAL	

CAT	SUBJ	CAUSAL/ENABLING FACTORS CLASS	SUBCLASS	STATE	PARTY	CAUSAL EVENT	SUP (X)
WX	1	WEATHER COND	PHYSICAL INFLUENCE	HURRICANE			X

EV	SUBJ'S	EVENT TYPE	EVENT CLASS	EVENT STATE	CAUSAL EVENTS
2	1	GROUNDING ACC	OUT OF CHANNEL	NO CONTROL	

CAT	SUBJ	CAUSAL/ENABLING FACTORS CLASS	SUBCLASS	STATE	PARTY	CAUSAL EVENT	SUP (X)
HF	1	CONT STRATEGY	REMEDIAL/EMER ACTION	NOT POSSIBLE	MAN		

CASE/ MC92015048 PORT/ MORMS SUBJECT/ MODU ZANE BARNES: GROUND DATE/ 25AUG92

--- COMMENTS ---

1. THE APPARENT CAUSE OF THIS CASUALTY WAS EXTREME WEATHER (HURRICANE) CONDITIONS WHICH FORCED THE VESSEL FROM ITS ANCHORED TO GROUNDED POSITION.

2. THE MODU POSSESSES AN APPROVED OPERATIONS MANUAL. HOWEVER, REGULATIONS ONLY REQUIRE THE OPERATOR TO MAINTAIN EVACUATION PROCEDURES. SINCE THE VESSEL WAS NOT IN PRODUCTION STATUS AT THE TIME OF THE INCIDENT, THERE WAS NO DESIGNATED OPERATOR "PER SE". NONETHELESS, IO INVESTIGATION AND DISCUSSION WITH DAVID EDELSON (READING & BATES ENGINEER) REVEALED COMPLIANCE WITH AN EVACUATION PROCEDURE TEMPLATE - THE SAME TEMPLATE PROVIDED BY R&B TO IT'S OPERATORS.

3. CHEMICAL TESTING WAS NOT CONDUCTED IN THAT IT WAS BELIEVED NON-BENEFICIAL UNDER THE CIRCUMSTANCES.

Appendix I - JACK-UP PERFORMANCE IN HURRICANE ANDREW

During Hurricane Andrew, a total of 9 jack-ups received some degree of damage. While the majority of the damage was relatively light, the exception to this was the *"MARLIN 3"*, a Bethlehem 265 mat rig. The Marlin 3's legs collapsed, and the rig drifted approximately 50 miles to the northeast running aground. The damage to jack-ups in Hurricane Andrew was limited since the majority of jack-up exposed were in shallow water, or were sufficiently far from the path of the hurricane to escape damage. A summary of the jack-ups exposed to Hurricane Andrew and damage received is included on Tables J.1 and J.2.

A diagram of Hurricane Andrew's path and relative jack-up positions is shown on Figure J.1. The jack-ups that received the brunt of Hurricane Andrew were located in water depth of 180 feet or less, and were all well within their maximum operating water depth. As discussed in Section 6, a jack-up's capacity to withstand storm loading varies linearly with water depth, and it can withstand far larger wave forces in shallow water as compared to deeper water. For example, a LeTourneau 116-C limiting wave height is approximately 50 percent larger for 150 feet versus 300 feet of water depth. As the majority of jack-ups are designed to survive a 10 year hurricane at their maximum operational water depth, its seems reasonable that the majority of jack-ups escaped Hurricane Andrew with relatively minor damage.

The jack-ups that were in deeper water and closer to their maximum allowable water depth were located on the west or weaker side of the hurricane path and 35 nautical miles or more away. These saw significantly reduced wind and wave forces than those MODUs closer to the storm. The closest deep water jack-up was the "OCEAN WARWICK", a Levingston Class III, located in 240 feet of water depth and approximately 40 nautical miles on the west side of the hurricane path. This jack-up probably encountered a significant wave height of 25 feet and maximum 1 minute wind speeds of 80 knots as given a hindcast by Oceanweather, Inc. The environmental conditions were much less than those to which the jack-up was designed for and it seems quite reasonable that this rig did not receive significant damage. Other deep water jack-ups were the "DUAL 41", a F&G Mod II, and the "ROWAN ODESSA", a Let 116, that were approximately 50 nautical miles on the left side of the hurricane path and in water depth of 260 feet and 248 feet respectively. These MODUs encountered a significant wave height of 18 feet and maximum wind speed of 65 knots. Again, these conditions were much less than their design limits.

If Hurricane Andrew had occurred at a time when jack-ups were typically drilling in deeper, or had taken Andrew taken a more westerly path such that the jack-ups in relatively deeper water MODUs saw conditions closer to their design limits, the number of jack-ups damaged, and the extent of that damaged, could have been very different.

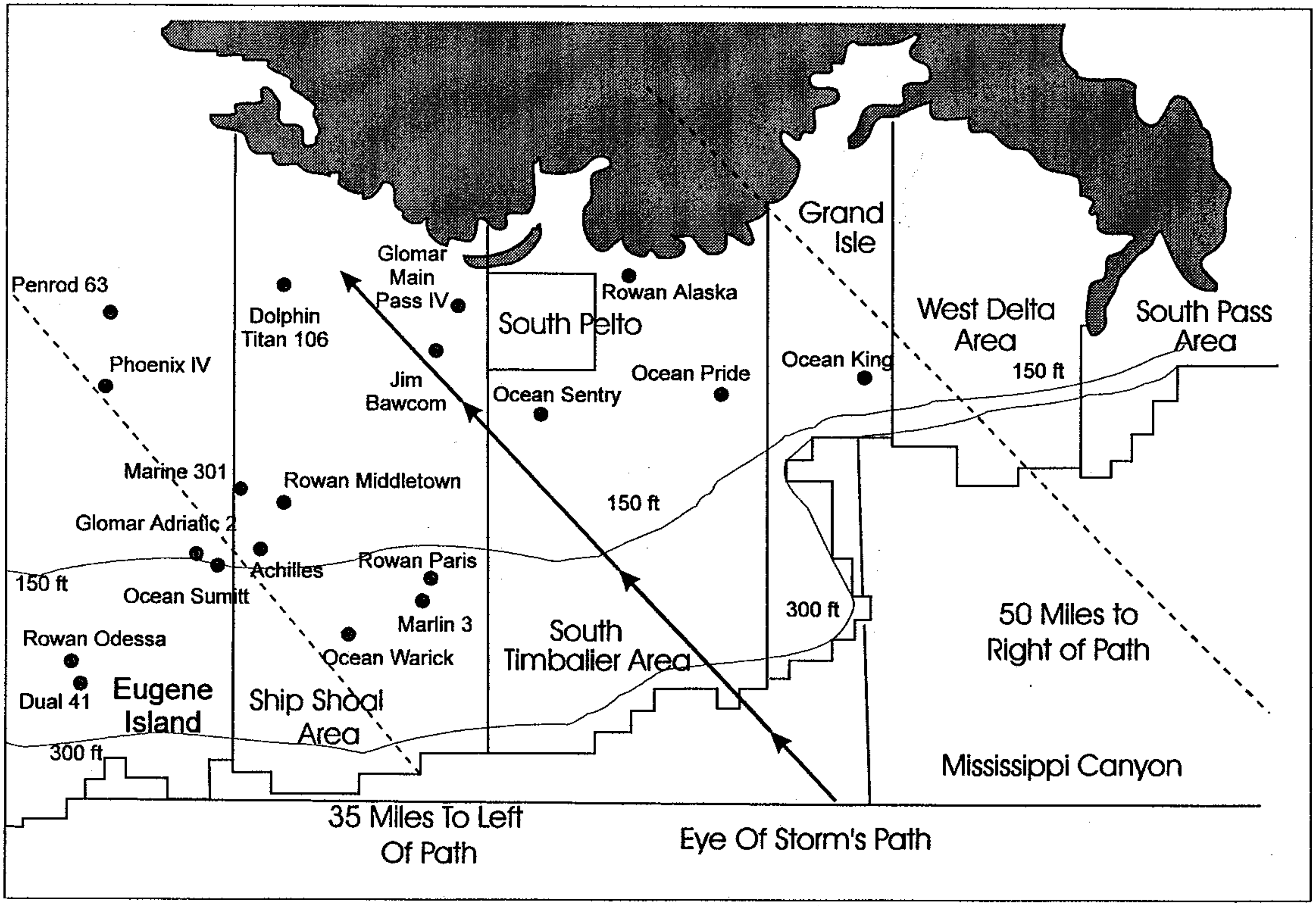
Table I.1 JACK-UPS DAMAGE DURING HURRICANE ANDREW

Name	Type	Water Depth	Estimated Maximum Weather Encountered
MARLIN 3	Beth 265	180 ft	Wind 100 kts
Damage: Leg collapsed, drifted 50nm, lost Mat			Wave 55 ft
ROWAN PARIS	Let 116-C	165 ft	Wind 106 kts
Damage: Leg Settled			Wave 55 ft
OCEAN SUMMIT	Lev 111	155 ft	Wind 80 kts
Damage: Leaned onto platform			Wave 45 ft
GLOMAR ADRIATIC 2	Let 116-C	145 ft	Wind 80 kts
Damage: Lost BOP & drive pipe			Wave 45 ft
OCEAN KING	Let 116-C	142 ft	Wind 95 kts
Damage: Listed a few degrees			Wave 50 ft
PENROD 63	Let 82-SD	42 ft	Wind 80 kts
Damage: Structural damage originally reported, but verified as antenna damage only			Wave 35 ft
JIM BAWCOM	Beth 250	36 ft	Wind 110 kts
Damage: Slide 50 feet over well head			Wave 40 ft
GLOMAR MAIN PASS IV	F & G Mod II	32 ft	Wind 110 kts
Damage: Damage: extent unknown Mobilized for shipyard repairs in Oct.			Wave 45 ft
DOLPHIN TITAN 106	Pen 100	16 ft	Wind 100 kts
Damage: Derrick fell on heliport and rig floor collapsed			Wave 32 ft

Table I.2 OTHER JACK-UPS EXPOSED TO HURRICANE ANDREW

Name	Type	Water Depth	Estimated Maximum Weather Encountered
DUAL 41	F & G Mod II	260 ft	Wind 65 kts Wave 32 ft
ROWAN ODESSA	Let 116-C	248 ft	Wind 65 kts Wave 32 ft
OCEAN WARWICK	Lev 111	240 ft	Wind 80 kts Wave 47 ft
ACHILLES	BMC JC-250-MC	145 ft	Wind 80 kts Wave 45 ft
ROWAN MIDDLETOWN	Let 116-C	100 ft	Wind 90 kts Wave 45 ft
OCEAN PRIDE	Beth 150-MS	96 ft	Wind 110 kts Wave 60 ft
MARINE 301	F&G Mod II	65 ft	Wind 80 kts Wave 43 ft
OCEAN SENTRY	Beth JU-200-MC	54 ft	Wind 110 kts Wave 60 ft
HERCULES	Beth JU-100-MC	54 ft	Wind 110 kts Wave 60 ft

Figure I-1 Jack-Up Positions During Hurricane Andrew



Appendix J - INFORMATION ON MODUS IN PAST HURRICANES

Hurricane FLOSSIE - 1956

Yr/Mo/Day	Name	Type	Comments
560929	Carter Mart	Submersible Drill Barge	Slid 40' from location, slot end buried 34', salvaged
560929	KERR McGEE 40	Submersible	Settled, topside damage, hit, wellhead abandoned
560929	KERR McGEE 44	Submersible	Settled, topside damage, hit, wellhead abandoned
560929	K.S. Adams	Tender	Beached when attempted to tow to shelter
560929	Phillips Rig 42	Submersible	Slid 500', Mississippi Delta, quarters damaged
560929	CATC Tenders	(2) Tenders	Broke from moorings, drifted 20 miles (25'WD)
560929	(2) LSTs	Drill Barge	Anchor line failures (not adrift) - 1 bow damaged platform

Hurricane Flossie was one of the first that had hit the Gulf of Mexico after the advent of drilling activity offshore. An excellent paper was prepared by J.R. Graham and J.E. Pike [1] that described some of the casualties. Flossie was only a Category 1 hurricane. It was not until the afternoon and evening of September 29, 1956 that it became evident that Hurricane "Flossie" was going to sideswipe the lower Mississippi Delta area. It was too late for any of the drilling crews and other personnel in the Grand Isle and Mississippi Delta areas to do much but shut down the rigs and run.

Reference: "Hurricane Flossie" - Knowledge & Experience Gained for Offshore Drilling Equipment [1]

The *Carter Mart*, a Morris and Hamilton submersible drilling barge, was drilling a well south of Cocodrie, Louisiana on the west side of Timbalier Island in 25 ft water depth. The rig was ballasted onto the bottom with a bearing pressure of 280 pounds per square foot. Wave action against the lower hull caused it to swing around the wellhead approximately 120 degrees. The template jacket was damaged. The barge also moved approximately 40 feet away from the center of the well and the action caused the slot end of the barge to dig itself into a hole where the bottom of the barge was 34 ft below the surface.

Kerr-McGee Rigs 40 and 44 were close by. The Kerr-McGee rigs exert a higher bottom pressure than the *Carter Mart* and thus are more resistant to lateral forces. Both rigs settled in the bottom due to their own weight and actually damaged the top side structure by collision with the wellhead. The wells were lost. (Note: *Kerr McGee's* practice was to design rigs to a high bearing pressure. *Rig 68* had an average of 1140 psf and *Rig 73* had 900 psf).

Reference: Oil & Gas Journal, October 1, 1956[2]

Both submersibles were located in South Timbalier area and one had 14 men on board. One of the barges moved about 5 ft off location.

The YF Tender *K.S. Adams* was drilling in the Bay Marchand area Block 4. Phillips decided to remove the barge and tow her to shelter. The tug had insufficient horsepower and the vessel eventually beached. The normal procedure at that time in handling a tender in storm conditions was to drop the mooring chain or wire rope and let the tender swing on the stern anchor. In the case of the *K.S. Adams* it is reported that the anchor was too small (5000 pounds) and that the 1-1/4" chain was too small and old, and thus the need to tow the vessel in.

The submersible barge *Phillips Rig 42* was located west of Mississippi Delta 47. The barge moved approximately 500 feet and the house structure was severely damaged.

Lessons Learned: Hurricane FLOSSIE

Reference: Oil & Gas Journal, October 1, 1956[3]

Two tenders owned by the C.A.T.C. group broke from their anchors during the peak of the storm Sept 24. With skeleton crews aboard they drifted south about 15 to 20 miles before being taken into tow the following day.

Reference: World Oil, November 1956[4]

Two LSTs had anchor chain breakages but did not go adrift. The bow of one brushed a platform but did little damage.

There were several important lessons learned stated by the authors[1] in Hurricane Flossie:

1. The submersible type of barge, which is economical to build and is quite safe in reasonably shallow water, up to say 40 ft. will walk on the bottom in heavy storm conditions unless it is tied in place with piling or by spuds driven into the bottom. It is our opinion that all such barges should have a spudding or piling arrangement to prevent the movement of the barge during storms.

2. The damage to the *Carter Mart* was the cause of a near disaster. It is recommended that such slotted barges operating in the open seas be built with cofferdams around the slot so that, in the event of contact or damage between the barge and the jacket structure, this damage cannot be of serious consequence.

3. Communication systems must be of the finest quality and should include contact between all stations, shore bases, Weather Bureau, tugboats and other marine equipment.

4. We question the advisability of any connection between the wellhead and the structure during a storm. From what we have seen, we believe it is probably a better practice if no connection exists between the two if it becomes necessary for the crew to abandon the rig.

5. There has been much damage caused by floating objects, vessels, barges, and other craft as a result of inadequate fender systems or mooring systems against the structures. After studying practically all of the offshore equipment, we are of the opinion that there has been no satisfactory fender system developed, and that the safest means is to anchor the floating equipment adjacent to the structures, but not in contact with it.

6. This will come as no surprise to anybody, but self-propelled equipment is considerably safer in storm conditions than is non-propelled equipment. Further, when a storm develops, everyone wants a tugboat and confusion is widespread.

7. It is estimated that approximately one-third of the total oil reserves in the United States are out in the Gulf of Mexico. To date, little production of these reserves has been established. What is happening is that the drilling contractors and production companies are locating their fields. We anticipate that in the next 5 years there will be a trend toward production, underwater pipelines will be established, collection and processing stations will be greatly increased. Structures are now being built in 100 ft. of water. The U.S. Coast Guard has established reasonable rules for certain features of lighting, foghorns, and other communications to protect the platforms from shipping. As these structures are erected farther from shore, the communications between drilling and producing structures and shipping will have to be improved. It must be borne in mind that one well in, say, 100 ft. of

water, represents an expenditure of approximately 1 million dollars. The productivity of that well may reach 10 million dollars or more. Therefore, there is not only a condition hazardous to navigation, but there is also a considerable financial risk to both the shipping and petroleum people.

Our experience in the offshore industry has been extremely interesting and informative. Many problems have not been resolved and I do not believe anyone can properly claim to be an expert in this field. We are all learning and hope to profit by our experiences. It is quite possible that a new drilling technique will be developed which will allow drilling and producing from underwater stations or from floating structures. I believe, however, that we can be assured that the future years will see a tremendous development in the production of petroleum products in the Gulf of Mexico."

Further Information on Lessons Learned[4]

Experience gained: more study to be given to types of storm moorings.

Types of storm moorings are still a point of discussion between operators. Some reported great success with anchor chains, with no breakage. Others said there was some breakage but the tenders held to their moorings. One company said all its anchor chains broke while wire anchor lines held fast. The same company reports it is putting two 1500 pound anchors on all its tenders for additional security in future storms.

When the storm hits, the tender will move far enough away from the rig to enable it to swing free in a 360 degree arc - will cast off all lines but the storm anchor. The extra anchor will be put over the side with wire line, ready to drop should the first anchor mooring break or slip.

Hurricane AUDREY - 1957

Yr/Mo/Day	Name	Type	Comments
570626	(2) CATC TENDERS	(2) Tenders	Broke moorings, drifted 45 miles, grounded E. Cameron
570626	GEORGE READING +1	(2) Tenders	Broke moorings, drifted 45 miles, grounded E. Cameron
570627	ED MALLOY (Dry Dock)	Submersible Drilling Barge	Sank, structural collapse, 6 escaped in raft
570626	MR GUS 1	Bethlehem Jackup	Tilted in April by a storm was put upright by Hurricane AUDREY but in the process was damaged so salvage intact became impractical
570626	OFFSHORE 54	Offshore Jackup	Settled, jacks in bind, recovered
570626	HUMBLE GOODRICH NO. 6	Barge Collision	Caused blowout
570626	VINEGAROON	LeTourneau 2 Jackup	Settled 7' in 35' WD @ W. Cameron 67
570626	KERR McGEE 40	Submersible	Settled, waves overtopped, extensive deck equipment damage
570815	DEEPWATER 2	LeTourneau 4 Jackup	Collapsed while drilling after hurricane

Reference: Oil & Gas Journal, July 8, 1957[6]

C.A.T.C. Group: Four tenders broke away from their platforms and dragged anchor for some 40 to 50 miles before washing aground near Cameron. Two of these were owned by Reading & Bates Drilling Co., doing contract work for the Group.

Biggest equipment casualty was a mobile drilling platform, the *Ed Malloy*, owned by the John Mecom interests of Houston. Six crewmen left aboard the rig took to life rafts and were rescued by plane the next day. The *Ed Malloy* was designed similar to a floating dry-dock with the dock submerged on location and a drilling barge section supported by cribbing above the water.

The cribbing gave way and the barge settled horizontally on one end of the dock. The wing of the dry-dock was knocked off, but the remainder was intact.

Mr. Gus: This famed offshore mobile drilling platform of Glasscock Drilling Co., an earlier victim of a Gulf storm, got a backhanded assist from Audrey.

Mr. Gus had been tilted on one side and was undergoing salvage work to right it.[8] Salvage crews abandoned work when the hurricane approached. The high wind and waves of Audrey flopped the big structure back into an upright position.

Reference: Oil & Gas Journal, September 2, 1957[9]

(Referring to *Mr. Gus*), the upper hull of the big offshore drilling platform was cut up and hauled ashore as scrap after a backlash from Hurricane Audrey made salvage intact impractical.

Reference: Oil & Gas Journal, September 2, 1957[9] *and Petroleum Engineer, August 1957*[10]

The *Offshore 54* was operating in 103 ft water in Vermilion 164 and suffered minor damages. The foundation settled causing the platform to list and put the jacks in a bind. The rig was later righted and resumed drilling.

Another mooring problem that led to a problem with the oilpatch was as follows:

Humble Oil & Refining Co.: A barge blown loose by the storm struck *Humble's Goodrich No. 6* at Weeks Island, causing it to blow wild.

Reference: The Petroleum Engineer, August 1957[10]

The *Vinegaroon* rode out the full fury of the storm and came out practically unscathed. It settled 7 ft in 35 ft water depth in West Cameron Block 67. It had commenced drilling again by July 2.

Kerr McGee Oil Industries Rig 40 suffered extensive damage of deck equipment. Wave action worked the mobile unit into the ocean floor until water broke over the platform and caused a slight list.

Reference: Oil & Gas Journal, September 1957[12]

Three men were injured when one leg of the *Deepwater No. 2* suddenly gave way. The injured, along with some 20 other crew members, were rescued by nearby boats as the vessel toppled in 25 ft. water in the Bay Marchand area off Louisiana. (Note: it is *not* known whether or not this was hurricane related in any way.)

Hurricane CARLA - 1961

Yr/Mo/Day	Name	Type	Comments
610911	PENROD 50	Penrod Submersible	Listed sharply, breaking off wellhead, Grand Isle
610911	PENROD 52*/PETREL	6-leg Jackup	Drifted 55 miles off location in Eugene Island 198 to Vermilion 162
610911	LOUIS OFFSHORE DELTA 1	F&G Submersible	Slewed 180° near W. Cameron, 6 ft water in pumproom
610911	SEDCO 22	F&G Submersible	Damaged Ship Shoal 107, engine room flooded
610911	MR CHARLIE	Submersible	Washed ashore; water in machinery and living quarters
610911	SHIP SHOAL /Gulf	(3) MODU	Shifted on location
610911	BAY MARCHAND 2	(4) MODU	Listing and damaged

Drill barge *Union Barge A* slid 10 ft and lost the BOP, walkways and saltwater lines.

Reference: World Oil, October 1961[15]

Penrod Drilling Company of Dallas reported *Rig 50*, drilling below 15,000 feet near Grand Isle, Louisiana, listed sharply, breaking off the wellhead. *Rig 52*, which had just finished drilling a dry hole for Placid Oil Company 55 miles south of Marsh Island, Louisiana, disappeared for several hours. The drilling barge, valued at more than $7 million, was found by a helicopter team 50 miles away in relatively good condition.

Louisiana Delta Offshore Corporation's *Rig 1*, a submersible barge drilling near West Cameron, Louisiana had 6 feet of water in the pump room. (Ref. Oil & Gas Journal gives this as 54 ft water depth.)

Reference: Oil & Gas Journal, September 18, 1961[16]

After the storm subsided, it (Penrod) found no sign of its $8 million *Rig 52*, which had been preparing to abandon a wildcat for Placid Oil Co. in 100 ft of water in Block 198 of the Eugene Island area. Early Thursday the six-legged platform was spotted 50 miles to the northwest in Block 162 of the Vermilion area. It was upright, but the extent of damage was unknown.

Penrod's *Rig 50* was damaged on location near the southeast end of Grand Isle. It was below 15,000 ft. on a test for Hunt Trust. The storm broke off the wellhead and left the platform listing badly.

A heliport platform was missing from an offshore installation in Ship Shoal area. One self-contained drilling platform was found to be listing and three mobile platforms shifted on location.

Reference: Oil & Gas Journal, September 25, 1961[17]

Southeastern Drilling Company's *Rig 22*, in Ship Shoal 107, went to the J. Ray McDermott shipyard last week for a 2-3 week repair job costing several hundred thousand dollars. Water washed through the engine room and caused heavy damage.

Ocean Drilling and Exploration Company's *Mr. Charley*, a submersible drilling barge, (reference Pipeline Industry, September 1964, indicates South Pelto Block 19) also went ashore for some $150,000 in repairs. Water washed into machinery and living compartments.

Reference: Hurricane Winds, Waves and Currents, Pipeline Industry, June 1964[18]

There were three MODUs reported to have been damaged in Ship Shoal area of the Gulf.

There was a Mobile Drilling platform moved about 55 miles from Eugene Island 198 area to the Northwest to Eugene Island 162 .

There was scour damage around a mobile drilling platform in High Island 160.

Reference: Pipeline Industry, October 1964[22]

Union Producing Company *Drilling Barge "A"*, which was drilling in Block 173 West Cameron area, rode out hurricane Carla successfully, but not without sustaining substantial damage. The barge was shoved some 10 feet off location and lost, among other things, its blowout preventer platform, several walkways, and two saltwater lines as well as all the groceries aboard.

Lessons Learned from Hurricane CARLA

Reference: World Oil, October 1961 15

Anchoring: Damage from inadequate mooring resulted from both Flossie and Carla. Suggestions for future storms include putting two 1500 pound anchors on all tenders. When a storm hits the tender should be able to swing free in a 360 degree arc with all lines cast off but the storm anchor. The extra anchor should be put over the side with a wire line, ready to drop should the first anchor mooring break or slip.

Hurricane HILDA - 1964

Yr/Mo/Day	Name	Type	Comments
641003	BLUE WATER 1	Santa Fe Semi-submersible	Capsized due to lack of airgap
641003	OCEAN DRILLER	Semi-submersible Odeco 3C	Broke 2 of 9 anchor chains; dragged 7 chains. Seas hit deck. Manned, 14 men. Moved 15 miles from location.
641003	BREWSTER BARTLE	Drill Barge	Sank in 180 ft. of water in Eugene Island 276
641003 ST 11	HUMBLE TENDER	Tender	Broke anchor lines, drifted 150 miles from S. Marsh 16
641003	MARGARET	Submersible	Minor damage
641003	SCORPION	LeTourneau 1 Jackup	2.75 deg list due to scour. Lost bell nipple & 500 bbl mud
641003	VINEGAROON	LeTourneau 2 Jackup	Minor damage
641003	PENROD 51	Penrod Submersible	Slid a few feet & slewed
641003	PENROD 50	Penrod Submersible	Bent conductor pipe on Main Pass 6
641003	JULIE ANNE	LeTourneau 3 Jackup	Slight list; minor damage
641003	DIXILYN 250	LeTourneau 21S Jackup	Bent & broke conductor pipe
641003	MOVIBLE Rig 2	Submersible	Bent spuds
641003	(Pure Oil)	Drill Barge	Suffered scour in Eugene Island 32
641003	KERR McGEE 40	Submersible	Minor damage; Ship Shoal 28
641003	STORMDRILL 1	Bethlehem 80 Mat Jackup	Slid 10' sideways

Reference: Modern Shipping Disasters[27]

The American semi-submersible drilling barge *Blue Water I* capsized and sank in the West Delta area in lat. 28°50'28"N, long. 89°37'23"W, during the ferocity of hurricane "Hilda" when it struck the Gulf of Mexico coast of Louisiana on October 6, 1964. There were no casualties but the barge, valued at $7.5m, was declared a total loss.

Reference: Oil & Gas Journal, November 9, 1964[28]

Blue Water Drilling, whose *Blue Water No. 1* rig lies upside down in West Delta Block 134, says it will make a "diligent effort" to save the bottle-legged floater and put it back to work.

Reference: Oil & Gas Journal, October 12, 1964[24]

Further, there were such near misses as a manned floater dragging anchor 10-12 miles and a tender breaking loose from its anchor chain.

In numerous cases, the storm left jackups and submersible barges listing. Contractors say the storm apparently scoured the sea bottom beneath the legs or hulls.

For the most part, only tenders were towed to sheltered ports. Other equipment customarily rides out such storms on location.

The bottle-legged *Blue Water No. 1* of Blue Water Drilling and the V-shaped *Ocean Driller* of Ocean Drilling & Exploration Co. had no self-propulsion and chose to ride it out.

Blue Water's $5.5 million floater was drilling for Shell in 210 ft. of water in West Delta Block 134, some 100 miles east of the path taken by the eye of the storm. The crew evacuated the rig at midweek after cementing surface pipe and setting a cement plug. The platform was secured with eight anchors.

When observed Monday morning the platform was floating upside down but still on location. One corner was tilted up, and the opposite corner was tilted down. A workboat crew was sent out to keep watch and the platform went under at 6:40 a.m. Tuesday. R. McLean Stewart, New York, chairman of Austral Oil Co., principal owner of Blue Water Drilling, says the anchors and mooring line spring buoys apparently were still in place.

"She went down in the middle of her mooring" says Stewart. "Obviously some structural damage must have occurred." According to Stewart, one of the platform's column stabilizers might have been punctured by an object hurled against the vessel by the waves kicked up during the storm. If this did happen, the platform possibly would have shipped water and listed, enabling the waves to capsize here. When she shipped enough water, she sank.

Ocean Drilling & Exploration was more fortunate. ODECO's superintendent of floating vessels, Max Harding, and a crew of 13 remained aboard the company's V-shaped *Ocean Driller* and safely rode out the storm. This was the only instance where personnel remained offshore during the hurricane. *Ocean Driller* was on an ODECO well in 210 ft of water in Ship Shoal 275. It rode out the storm in operating position 70 ft submerged with 50 ft clearance to the top deck. "A number of waves struck the top deck," says Laborde. During the height of the storm, a local squall, or some other freak condition, suddenly caused wind direction to shift momentarily. This stress snapped two of the vessel's nine anchor chains and the platform drifted 10 to 12 miles westward with the remaining seven anchors dragging all the way.

"Roll and pitch never exceeded 2 degrees in any direction, and there was no structural damage of any kind. The crew recorded anchor chain tensions as great as 170,000 lbs. and that was before the storm prevented their reaching the tension gauges and before the chain broke."

...the drilling rig of Brewster-Bartle went to the bottom in 180 ft. of water in Eugene Island's Block 276.

Humble, an LST drilling tender in South Marsh Island's Block 16, broke loose from its single anchor chain during the storm but later was spotted, boarded, and placed under tow. Prior to Hilda, *Humble* had backed it off the platform and hoisted three of the four anchors to allow it to swing with the storm. There was no time to tow the tender ashore before the storm hit.

Reference: World Oil, November 1964[23]

Since nearly all the tenders were brought into sheltered waters, little damage was reported. Humble Oil & Refining's *B Platform Tender ST-11* in South Marsh Island Block 6, a converted LST, broke its anchors and drifted 150 miles southeast of its location. Damage was minor.

Forty-three submersible, self-elevating and floating-type platforms were reported off Louisiana's coast shortly before Hilda hit. With the exception of *Bluewater I*, they all came through with relatively minor damage.

Ocean Driller snapped chains on six of nine 10,000 pound anchors and was buffeted 15 miles off location in 130-150 miles per hour winds and 50-70 ft waves with 14 men aboard.

....ODECO's submersible unit *Margaret* had minor damage.

Zapata Offshore's self-elevating unit *Scorpion* had a 2-3/4 degree list due to scouring of the ocean floor, lost a bell nipple and about 500 bbls of mud. The firm's self-elevating unit

Vinegaroon had minor damage. Seaweed was found in the drawworks more than 45 feet above the water surface.

Penrod Drilling's submersible *Unit 51* shifted a few feet off location, apparently bounced up and turned partly around. Submersible *Rig 50* bent conductor pipe on Mobil well in Main Pass Block 6. Damage was minor.

Dixie Lynn Corporation's self-elevating unit *Julie Ann* had a slight list with minor damage. The firm's self-elevating *Unit 250* bent and broke conductor pipe.

Movible Offshore's submersible *Rig 2*, drilling for Shell in Eugene Island Block 128A, reported two of four spuds bent. Cost to repair: $50,000.

Drilling barge was scoured under in Eugene Island Block 32, working for Pure Oil.

Kerr-McGee's submersible *Rig 40* in Ship Shoal Block 28 field suffered minor damage.

Thirty-one more mobile units reported either minor or no damage.

Nearly half of the mobile units that weathered the storm were shifted off location, ranging from a few inches to several feet.

Reference: OTC "Performance of Mat Supported Jackup Drilling Rigs"[26]

Stormdrill 1 moved laterally 10 ft. during the hurricane and had additional sinkage of 3 ft.

Hurricane BETSY - 1965

Yr/Mo/Day	Name	Type	Comments
650909	PENROD 52*/PETREL	6-leg Jackup	Capsized moving on, then hit by Hurricane BETSY in Eugene Island 199
650909	MAVERICK 1	LeTourneau 21 Jackup	Overturned in 220 ft water depth in Main Pass 300
650909	BLUEWATER 1	Semi-submersible	Capsized; was torn apart in West Delta 119 before salvage
650909	STORMDRILL 2	Bethlehem 150 ft. Mat Jackup	Slid 100' sideways, shifted 90ft north and 35 ft west destroying the well in W.D. 45
650909	MR CHARLIE	Submersible	Slid 125' off location at W Delta 27
650909	ELDORADO	Submersible	Shifted off location in W. Delta 20
650909	VINEGAROON	LeTourneau 2 Jackup	Moved 10' off Main Pass 41
650909	STORMDRILL 1	Bethlehem 80 ft.Mat Jackup	Slid 35' sideways

Reference: Modern Shipping Disasters 1963-1987[27]

The American jackup drilling rig *Penrod Rig 52*, valued at $2.5m, capsized while under tow in Eugene Island Block 199, offshore Louisiana, on August 29, 1965. The rig subsequently broke into three sections during the ferocity of Hurricane "Betsy" on September 10, 1965.

Valued at $5.7m, the American jackup drilling barge *Maverick I* was destroyed during the ferocity of Hurricane "Betsy" in the Gulf of Mexico off the Mississippi Delta in lat. 29°16'45"N, long. 88°46'46"W, on September 10, 1965.

Reference: World Oil, October 1965[30]

C.A.T.C. had seven tenders working offshore. They were moved into the Mississippi River near Point A La Hache before the storm. But, Betsy pushed three of them aground, and they will be difficult to recover.

Betsy took a heavy toll in mobile drilling units. Ten (10) of the 46 units working offshore reported at least minor damage (up to $25,000).

Zapata Offshore's $6 million LeTourneau-type jackup rig, *Maverick I*, drilling for Chevron in Main Pass Block 300, disappeared without a trace in 220 ft of water.

Penrod's self-insured $4 million Seadrill-type six-legged *Rig 52*, which had turned over on its side in Eugene Island Block 199 last August, had the lower hull broken away from the upper hull.

The *Bluewater 1*, valued at $5.5 million before it sank during Hilda, was torn to pieces in West Delta Block 112.

Several of the mobile offshore rigs were moved off location from 8 ft. to more than 100 ft. Estimates are that it costs $25,000 - $30,000 to move a small unit back on location, and $60,000 - $70,000 for a large unit.

The *Stormdrill II* 3-legged jackup unit, drilling at about 5,000 feet in West Delta Block 45 for C.A.T.C., was shifted 90 ft. north and 35 ft. west of the location. The lower mat of the rig moved over the well and destroyed it. The rig was not damaged.

Ocean Drilling and Exploration Company's giant offshore drilling unit *Mr. Charlie*, drilling for Gulf in West Delta Block 27, was pushed off location about 125 feet. ODECO's *El Dorado* was shifted off location in Gulf's West Delta Block 20.

Zapata Offshore's *Vinegaroon*, drilling for Chevron in Main Pass Block 41, was moved about 10 feet off location.

Forty-one (41) men on an LST drilling tender loaded with 30,000 ft. of drill pipe, 3200 sacks of cement and 1500 sacks of drilling mud rode out the eye of the storm near the mouth of the Mississippi. The men, who reported the wind gauge registering 150-170 miles per hour, came through without injury. A powered tender with 44 men aboard rode out the storm in the Bay Marchand area with no injuries and little damage.

Reference: OTC "Performance of Mat Supported Jack-Up Drilling Rigs"[26]

Stormdrill I moved 30-40 ft. in hurricane Betsy and had additional sinkage of 7 ft. *Stormdrill 2* moved laterally 100 ft. and had an additional sinkage of 5 ft. during the storm.

Hurricane CAMILLE - 1969

In relation to Hurricane Camille, the Lloyd's List notes on August 25, 1969, "Not one mobile rig was lost or even seriously damaged." The primary reason is that most mobile rigs would have been well to the west of the storm.

Yr/Mo/Day	Name	Type	Comments
690817	TRANSWORLD 50	Bethlehem	Slid 2 ft. 70 ft. Jackup
690817	ST LOUIS	Odeco Submersible	Water damage in engine room when trying to move from Hurricane CAMILLE
690817	ROWAN 14	Drill Barge	Damaged

Reference: World Oil, October 1969[32]

Because of advanced warning, there was little damage to mobile drilling rigs.

Reference: Ocean Industry, October 1969[33]

Other equipment damage included four large drilling rig tenders belonging to Chevron. The vessels, some of them converted LSTs, were anchored near the Head of Passes in the Mississippi River. One tender was damaged in the anchorage when a nearby Japanese freighter dragged its hook and collided with it. Cost of repairing the tenders is estimated at $1 million.

Reference: Oil & Gas Journal, August 25, 1969[34]

Camille, a tight-centered hurricane with gusts up to 200 mph, began driving into shore in the day and by 3 p.m. had struck the South Pass 70 area located on the edge of the Continental Shelf.

Reference: Lloyd's List[35]

The areas in the direct path of the storm were South Pass, Main Pass, Breton Sound and Chandeleur Sound areas.

Chevron: Partial losses to four of their five tenders. However, all can be repaired.

Ocean Drilling and Exploration Company: Submersible rig *St. Louis* (rated water depth 30 ft.) sustained water damage in engine room when attempting to move the rig off location prior to the storm. It was sat down in too deep water.

Ref: OTC "Performance of Mat Supported Jackup Drilling Rigs"[26]

Transworld 50 had 2 ft. lateral movement in Hurricane Camille and a 4.5 degree tilt after the hurricane passed. It was in 41 ft. water depth.

Hurricane EDITH - 1971

Yr/Mo/Day	Name	Type	Comments
710917	PENROD 50	Penrod Submersible	Tilted due scour [35]
710917	JACK CLEVERLY	Drill Barge	Broke moorings and grounded [35]

Hurricane CARMEN - 1974

Yr/Mo/Day	Name	Type	Comments
740908	TWO R 4	Drill Barge	Damaged
740913	PENROD 60	LeTourneau 53 Jackup	Damaged; lost all legs & derrick. The rig was reported tilted but not capsized.

Lloyd's List reported on September 13th that several drilling units have apparently been nudged off locations.

Reference: Lloyd's List

At this time, towing services are in short supply in this area as the majority of tugs are being employed by oil companies in re-establishing drilling rigs and platforms which were shifted off their positions by hurricane Carmen. In consequence of this, steam tanker *Energy*, which is currently aground, has been forced to wait several days before tugs become available to assist her.

The only damaged rig established by Monday was jackup drilling barge *Penrod 60*, drilling off Eugene Island. The rig is tilted but not capsized. Several drilling units have apparently been nudged off locations.

Reference: Lloyd's List

Penrod Drilling Company's jackup drilling barge *Penrod 60* was ripped off its location on Eugene Island Block 313. It was recovered a day after the storm but had lost its legs, derrick and drawworks. Penrod's jackup *Penrod 54*, which had been working on the same block, was undamaged. Several inland drilling barges were capsized or damaged by rising water.

Reference: Private Communication SIPM, 5 December 1988 (158)

The wave height applicable to the *Penrod 60* was approximately 10m.

Hurricane ELOISE - 1975

Yr/Mo/Day	Name	Type	Comments
750922	MARINER 2	Santa Fe Semi-submersible	Boat fender damaged
750922	OCEAN QUEEN	Odeco Semi-submersible	Listed during hurricane (when evacuated)
750913	MARGARET	Odeco Submersible	Damaged; broke up in shipyard before repairs carried out

Reference: Modern Shipping Disasters 1963-1987[27]

While at New Orleans for repairs to damage sustained during hurricane "Eloise", the American non-propelled drilling barge *Margaret* partially sank on October 9, 1975 then broke up six days later and completely sank. She was insured for $3m.

Reference: Lloyd's List

Hurricane Eloise did little damage to offshore petroleum installations. Semi-submersible drilling barge *Ocean Queen* was found listing slightly but has since been uprighted.

Ocean Drilling & Exploration Company's drilling barge *Margaret* broke up and sank last week while docked at Avondale Shipyards Inc. near New Orleans. The barge, a 65 ft. submersible which began service in 1957, had been towed to the shipyard for repair of damage sustained during hurricane Eloise.

Hurricane ALLEN - 1980

Yr/Mo/Day	Name	Type	Comments
800813	DIXILYN FIELD 81	LeTourneau 150 Jackup	Capsized & sank after 20' extra penetration in 102 ft. water in N. Padre Island 957. It was working for Atlantic Richfield.[36, 37, 38]
800808	SALENERGY 1	Bethlehem 250 Mat Jackup	Shifted position
800808	J STORM 7	Bethlehem 375 Mat Jackup	Skidded due scour; bent drive pipes and BOP[35]
800810	POOL 50	Pool Jackup	Slid
800810	MR GUS 2	Bethlehem 150 Mat Jackup	Slid
800810	SABINE 1	Bethlehem 200 Mat Jackup	Damaged substructure & wellhead/BOP; was working for Samedan[35]
800810	FJELL DRILL	Bethlehem 250 Mat Jackup	Tilted; drill caisson missing; leg cracks. Operator was Shell on Mustang Island Block A20.
800811	HARVEY H WARD*	Bethlehem Mat Jackup	Capsized & sunk after mud slide; legs sheared off
800808	W TRITON 4	LeTourneau 82 Jackup	Bent drive stacks & BOPs[35]
800808	TELEDYNE 17	Bethlehem 250 Mat Jackup	Shifted position due scour[35]

On August 7, 1980, while positioned at Padre Island Block 957, offshore Texas, about 29 miles northeast of Port Mansfield, the Panamanian non-propelled self-elevating drilling platform *Dixilyn-Field 81* was shut down and evacuated due to the approach of hurricane "Allen". When the crew attempted to reinspect the platform four days later, it could not be located. It was finally found capsized and sunk in 102 feet of water, presumed to have been destroyed during the winds in excess of 120 miles per hour and waves of 50' that struck the south Texas coast due to hurricane "Allen" on August 9-10. The rig, valued at $30m, was declared a constructive total loss.

Note: This rig was constructed with insufficient preload capability to preload the soil for a 10-year storm condition. Additionally, the waterdepth it worked in was beyond its structural operating capability as limited by the designers.

On August 10, 1980 while jacked up about 22 miles east of Pilot Town, Louisiana, the American non-propelled jackup drilling barge *Harvey H. Ward* drifted due to the extreme weather effects of hurricane "Allen", until finally capsizing in 180' of water off the Main Pass area in lat. 29°09'N, long. 88°53'W. Insured for $22.5m (£9.45m), she was declared a constructive total loss.

Reference: Lloyd's List, August 18, 1980

Reported that the winds were recorded in excess of 120 mph with reports of waves reaching 50 ft.

Jackup drilling barge *Harvey H. Ward*, built in 1979 in Singapore and owned by Reading & Bates, capsized off Southwest Pass August 9th or 10th. No one on board at time owing to hurricane Allen. Barge was jacked up in Main Pass Block 151 but has reportedly drifted to South Pass Block 66.

Self-elevating drilling platform *Dixilyn Field 81* operating for Atlantic Richfield Company in North Padre Island area approximately 29 miles northeast of Port Mansfield, Texas: "Platform shut down and evacuated on August 7 due approach of Hurricane Allen."

Reference: Lloyd's List, August 15, 1980

Dixilyn Field 81 has been confirmed capsized and sunk at location in North Padre Island area Block 957. Waterdepth is 102 ft. and approximately 40 ft. of water is over the drilling unit at this time.

Self-elevating drilling platform *Fjelldrill* sustained an undetermined amount of damage due to the force of the storm. Operator Shell reports an aerial survey shows the rig is "tilted and its drilling caisson missing". The unit was drilling on Mustang Island Block A20 about 40 miles southeast of Corpus Christi.

Reference: Lloyd's List

Sabine I, owners - Houston Offshore International, Inc., working for Samedan Oil Corp. on Mustang Island Block 818, sustained damages during Hurricane Allen and is being towed to a shipyard for inspection and repair.

Reference: U.S. Coast Guard Report Harvey H. Ward[39]

The possible causes are outlined in this report. The most likely cause was that the bottom soils in which the *Harvey H. Ward* was positioned, failed, or slid causing the rig to capsize. *(Additional information indicates this is in a potential mudslide zone. The jack-ups was enroute to an approved, checked and suitable location, and the location was changed by the operator at the last moment. The new location was not subjected to the usual verification.)*

Hurricane ALICIA - 1983

Yr/Mo/Day	Name	Type	Comments
830817	APACHE	Bethlehem Jackup	Hit by supply vessel during evacuation. Minor damage to bow leg
830818	PENROD 87	LeTourneau 82 Jackup	Damage to BOP hoses
830818	APACHE	Bethlehem Jackup	Rig moved off location and wellhead and BOP stack missing

Reference: Noble Denton Damage Report[40]

On August 16, 1983, routine well logging operations were being carried out when Hurricane Alicia emerged as a threat to marine interests in the Gulf of Mexico. Operations immediately commenced to secure and abandon the rig. The crew began to remove the drill pipe so that a storm choke could be installed to secure the well. While attempting to remove the drill pipe from the hole, weather conditions began to rapidly deteriorate. Some movement of the rig was noted as evidenced by the relationship of the rotary table to the wellhead bell nipple. It was feared that the movement of the rig might prevent installation of the storm choke. The storm choke was successfully installed leaving approximately 7800 ft. of drill pipe in the hole. At 06:30 hrs. on that date while attempting to remove the toolpusher from the rig, the utility vessel *Panama City* collided into the port column of the rig damaging it. After the passage of the hurricane the rig was re-boarded and it was discovered that the rig had been moved off location during the storm, and the wellhead, including the blowout preventer stack, were missing. Estimated loss - $460,000.

Hurricane DANNY - 1985

Yr/Mo/Day	Name	Type	Comments
850815	POOL 50	Pool Jackup	Slid off location; leaned towards fixed platform; could not jack down. Total Loss.[38]

Reference: Private Communication SIPM[41]

The *Pool 50* rig began listing towards the platform because of bottom wash-out (scour) due to hurricane Danny. Tugs were used to pull the rig away from the platform. Parts of the jackup hull had to be cut away to remove it.

Hurricane ELENA - 1985

Yr/Mo/Day	Name	Type	Comments
850902	ZAPATA YORKTOWN	Semi-submersible SS2000	Evacuated. Broke 7 of 8 moorings. Drifted 15 miles [35]
85	OCEAN ROVER	Semi-submersible Ocean Victory	Broke moorings; adrift.

Hurricane JUAN - 1985

Yr/Mo/Day	Name	Type	Comments
851027	AMY DANOS	Liftboat	Sank in Ship Shoal area
851027	GLOMAR ATLANTIC	Drillship	Port anchor wire failed. Riser connections damaged.
851027	EUGENE ISL 44B	FSU Barge	Towbits failed, 40° list, capsized
851027	PENROD 61	LeTourneau 53 Jackup	Bow leg collapsed floated, hit Penrod 60, sank
851027	ELO	Liftboat	Sank in S. Timbalier
851027	INCA	Liftboat	Drifted then grounded; some leg damage
851027	LES WALTERS	Liftboat	Capsized. Structural damage to one leg [49]
851027	PENROD 60	LeTourneau 53 Jackup	Hit by Penrod 61. Minor damage.
851028	PAUL DANOS	Liftboat	Capsized. Legs bent. [48, 49]
851028	TECHE 1	Liftboat	Swamped & moved off position [49]
851028	SEA LIFT 4	Liftboat	Sank in Ship Shoal area [49]
851028	AM HOWARD	Liftboat	Punchthrough, cargo moved, capsized near Mississippi outlet [49]
851028	POWER 4	Liftboat	Capsized & washed ashore
851028	DIXILYN FIELD 80	LeTourneau 21 Jackup	One leg dropped 2.4', casing damaged, E. Cameron 320
851028	RUTH	Liftboat	Capsized; three legs damaged; was jacked up in Vermilion 144
851028	DIXILYN FIELD 76	Submersible	Slid sideways; damaged mat, casing, wellhead; W. Delta 18/5
851028	GULF ISLAND 4	Liftboat	Soil failure. Capsized. [49]
851028	MR CHARLIE	Odeco Submersible	Slid 17' over wellhead; damaged pontoons [47]

Reference: Lloyd's List, October 28, 1985

"Hurricane "Juan" approached Louisiana's "Gumbo" coast yesterday with 85 mph winds. The Coast Guard reported two people were missing from m supply vessel *Miss Agnes*, which sank in 30 ft. waves kicked up by "Juan" as it churned in the Gulf of Mexico towards an anticipated landfall before dawn today on the southeastern coast of Louisiana. A Coast Guard cutter responding to a radio distress call at 1630 hrs rescued two of the four people on board the *Miss Agnes* but could not find the other two in a search about 30 miles south of Morgan City, Coast Guard spokesman Keith Spangler said. He said another 50 people were stranded on vessels and oil rigs in the Gulf but there was nothing they could do until the seas calmed. The National Hurricane Centre predicted "Juan" would blow ashore before dawn today but said significant strengthening was unlikely before landfall.

At 2300 hrs the hurricane's centre was about 125 miles southwest of New Orleans and 75 miles from Grand Isle near lat 28 30N, long 91 18W and moving north-northwest at 15 mph. Three workers suffered broken bones last night as they were hoisted in a basket from an oil platform onto a crewboat off Louisiana, Spangler said. High winds slammed the basket against the rig. Ten workers awaited evacuation from an oil rig that collapsed about 30 miles southwest of Leeville, Louisiana. Spangler said the rig was sitting on the ocean bottom with the main deck barely above water. "Juan" lashed the Louisiana coast with 8 in. of rain and wind gusts of 50 mph.

Two oil rigs collapsed early today in the Gulf of Mexico towing 80 crewmen into seas turned violent by hurricane "Juan". The Coast Guard said one of the rigs, a jack-up, drifted into the other after seas knocked off its four legs. There were no reports of injuries. The 80 workers were in two 28-man escape capsules and one 44-man covered raft. A Chevron oil vessel was on her way to the scene to rescue the men.

Hurricane "Juan", which wrecked three offshore oil rigs as it crossed the Gulf of Mexico, today stalled near the central Louisiana coast and lashed the mainland with high winds, tornadoes and torrential rain. The Coast Guard said about 100 people on the rigs were stranded on rafts or on their damaged platforms and awaited rescue. A Coast Guard helicopter searched for an offshore oil rig that disappeared before dawn. Crewmen on another rig saw the Chevron platform in place south of Leeville at 0500 hrs but at 0646 hrs they "looked out and didn't see it", said Lt. Keith Spangler. The only survival equipment on the rig was a cork life raft, he said. Earlier in the morning 80 crewmen were forced into the water when a jack-up rig (*Penrod 61*) collapsed then collided with another rig (*Penrod 60*).

Twenty men were plucked from the water by Coast Guard helicopters and others were believed safe on life rafts and in escape pods equipped with provisions, officials said."

Reference Modern Shipping Disasters 1963-1987[27]

On October 28, 1985, while in the Grand Isle Block 86 in the Gulf of Mexico, the self-elevating drilling platform *Penrod 61* broke from her moorings during hurricane "Juan", drifted into the drilling platform *Penrod 60* and subsequently sank. There was no loss of life. The *Penrod 61*, which settled as a constructive total loss, was insured for \$36m (£25.17m), making it one of the largest losses of the year.

Reference: Noble Denton and Associates Inc. Analysis of Penrod 61

Hurricane Juan came late in the season, and no one believed it was likely to turn into a problem until it was too late to completely evacuate the Gulf Coast rigs.

At 3:00 in the afternoon on 27th October there were some popping noises coming from the legs of the *Penrod 61* and a 'shudder' was felt. By 5:30 the rig had taken on a lean of 2 degrees by the bow. Although the rig's operating manual indicated more than a 1 degree tilt should be compensated for....no one did anything.

By midnight the lean had increased to 4 degrees. The ability of the rig to resist the wave forces, with this inclination, was cut by about 35%. When the lean increased to over 4 degrees, they started to crank up the engines to jack it level. After the rig started to jack, for about 5 seconds the rig suddenly fell a short distance and stopped again. It fell in 3 or 4 more increments and finally was in the water.

The rig was still floating and drifted toward the sister rig, the *Penrod 60*. It finally collided with the *Penrod 60* and sank about 9 miles later. The sister rig, a mile or so away, did not collapse. The storm was coming from the south. The *Penrod 61* was facing north with its single bow leg...the one that caused the problems taking all the load. The sister rig was facing south with 2 legs rather than 1 resisting the overturning.

The bow leg of the *Penrod 61* had approximately 10 ft less penetration than the stern legs. The lack of preload capacity at the forward end of the rig, less than required by the ABS rules of the time, combined with the practice of jacking the substructure aft before preloading, caused the bow of the rig to take on increased penetration. Lack of response to this by personnel on board increased the probability of the casualty. It is likely that the jackup was close to its operational limits for a 10-year return period storm at this location.

The U.S. Coast Guard and the National Transportation Safety Board investigated the accident and came to the conclusion that it was a structural failure. The legal entities involved with protecting their clients put forward the structural weaknesses as the primary cause as an initial accusation, and after the hearings and the facts were presented, the experts eventually agreed that the additional penetration was the primary cause. The USCG and NTSB report is considered by most experts to be wrong, and the USCG report to be misleading.

Reference: NTSB Report

The National Transportation Safety Board determines that the most probable cause of the collapse of the *Penrod 61* was a structural failure of undetermined origin to its bow leg. Contributing to the collapse of the *Penrod 61* was the failure to inspect the legs of the MODU over their entire lengths. Contributing to the loss of life was the failure of the survival capsule to right itself after capsizing.[46]

Reference: U.S. Coast Guard Report

On 27 October 1985 at approximately 2230 local time, the jackup type Mobile Offshore Drilling Unit *Penrod 61* developed an out of level condition with the bow approximately 6 degrees or approximately 13 feet lower than the rest of the rig. The rig was jacked up in the bottom-bearing mode with a 50 ft air gap on the Outer Continental Shelf, Grand Isle Block 86, Gulf of Mexico, latitude 28 degrees 29'28"N, longitude 90 degrees 07'34" W. The rig was not drilling but secured for the passage of Hurricane Juan. At the time of the casualty, observed winds were from 55 to 60 knots and estimated seas were 30 to 35 feet and occasionally larger.

At 2300, an attempt was made to re-level the rig by jacking the rig up at the bow leg. As the jacking gear on the bow legs was engaged, the bow of the rig began to fall in sequential drops to the sea. The stern legs of the rig collapsed minutes later and the rig began to drift freely in the seas. The rig ultimately collided with *Penrod 60* which was jacked up with a 60' airgap at a location approximately one mile away.

Forty-three persons aboard *Penrod 61* were forced to abandon the rig as a result of its collapse. At 2320, thirty-nine persons aboard *Penrod 60* were forced to abandon their rig at the imminent threat of *Penrod 61* colliding with *Penrod 60*. All 39 persons aboard *Penrod 60* abandoned the rig in a covered 58 passenger lifeboat. Forty-one (41) of the 43 persons on rig 61 abandoned the rig in its two, 28-passenger survival capsules, 23 boarding the No. 1 capsule and 18 boarding the No. 2 capsule. One person abandoned the rig in an inflatable life raft and one other jumped overboard wearing only a life jacket.

The proximate cause of the collapse of the *Penrod 61* cannot be determined. The most probable cause was the structural failure of the bow leg due to the combined effects of metal fatigue and an increased penetration into the sea floor by the leg. The additional penetration resulted in the leg moving from a vertical to an angled position, decreasing its load-carrying capacity.

Dixilyn Field 76 Analysis

Seneca Resources owned the well that was being drilled by the *Dixilyn Field 76.* It was Well No. 5 located in West Delta Block 18, in 50 ft waterdepth.

After Hurricane Juan, on October 30th, the rig was reboarded and an inspection was conducted to evaluate the damages sustained. Initial inspection revealed that the wellhead and casing strings were no longer in place. There was no apparent leakage from the well. Divers found that the casing strings above the sea floor were bent over with the wellhead assembly being partially submerged approximately 21 feet below the waterline. The severe weather caused the rig to shift forward impacting the well and causing damage to the wellhead and mat of the submersible rig. Extensive damage was sustained to the forward portion of the rig mat. Divers later discovered that the casing strings were imbedded approximately 6-8 feet into the rig mat. The cost of the casualty was in excess of $5. million.

A number of factors contributed to the casualty. The rig had a leaky caisson which allowed the ballast tanks to leak down to water level, decreasing the average bearing pressure. Crew had not ballasted to the full extent of the ballasting capability, decreasing the bearing load. Operations manual guidance was not clear on the necessity to ballast at the location.

The ballast capacity ranged from 130 psf to 447 psf from port forward to starboard aft. The maximum achievable was 462 psf. The recommended was 500 psf.

Reference: Lloyd's List, November 1, 1985

American jackup drilling platform *Power IV*, owners - Gulf Island Marine, capsized and washed ashore during hurricane Juan, Grand Isle, Louisiana. *Power IV* aground Grand Isle area reporting leg damage. Lift barge *Inca* aground Grand Isle area. Lift barge *Elo* sunk South Timbalier area. Lift barge *Amy Dinos* sunk Ship Shoal area.

Reference: Lloyd's List, November 4, 1985

One of the three legs of the *Penrod 61* apparently punched through the sea floor causing the other two legs to buckle. The rig then floated into the *Penrod 60* and sank. Both units were working for Chevron on Grand Isle Block 86, off Louisiana. One crew member was killed while the two rigs were being evacuated.

Three men trapped on board supply barge *A.M. Howard* perished after the unit capsized in a River Mississippi outlet. She was owned by Cardinal Wirelines Specialists of New Orleans.

Reference: Lloyd's List, January 30, 1986

Wreckage of jackup drilling rig awash in lat 28 54 34 N, long 90 53 31 W. United States Coast Guard reports no one has claimed ownership of leg and pad that remain from the jackup which was damaged during hurricane Juan. Buoy has been placed in position and marked hazard to navigation. Possibly remains of lift barge *Amy Dinos*, which went down in Ship Shoal Block 89, but unable to identify.

Hurricane CHANTAL - 1989

Yr/Mo/Day	Name	Type	Comments
890731	GULF ISLAND 4	Liftboat	Soil failure (tilted); after evacuation; all 3 legs broke
890731	AVCO 5	Liftboat	Capsized in 12' seas going to shelter. 10 lives lost.
890731	RANGER 6	Bethlehem 70 Mat Jackup	Soil failure (tilted 3 onto well), 5 evacuated
890731	ZAPATA NEPTUNE	Semi-submersible	Broke moorings, hit JFP 12 in GALVESTON harbor

Reference: Lloyd's List, July 31, 1989

A mobile oil rig (*Avco V*) capsized 20 miles offshore in the Gulf of Mexico just before dawn today possibly trapping 10 crewmen, the Coast Guard said. "There were an estimated 14 people on board. Three were picked up by passing fishing vessels and one was picked up by a Coast Guard helicopter." The other 10 are unaccounted for and it is suspected they may be trapped on board. The accident occurred in an area identified as Ship Shoal Block 123 about 20 miles off the Louisiana coast. The accident occurred in 25 ft of water. The area is about 200 miles north of the center of Chantal which was moving with maximum sustained winds of 50 mph and higher gusts.

Reference: Gulf of Mexico Newsletter, August 14, 1989[42]

The power of even a minor storm such as Hurricane Chantal should not be underestimated. The semi *JFP 12* received minor damage when the semi *Zapata Neptune* broke free of its mooring and collided with the other unit during the August 1st storm. Both rigs were grounded and tied up at a berth at the Port of Galveston; apparently the storm surge caused the Zapata rig to skid about 100 ft. and collide with the *JFP 12*. The rigs became entangled preventing the *Zapata Neptune* from drifting into the harbor. The *JFP 12's* control room reportedly sustained heavy damage, but damage to Zapata's rig is described as minimal.

The only problem involving an exploratory drilling rig occurred to Atlantic Pacific Marine's mat supported jackup *Ranger 6*, which listed about 3 degrees due to the sea floor scouring. The rig was positioned alongside an Arco platform in West Delta Block 38 working over a well when the storm developed into a hurricane. The unit was in the process of being evacuated when it began to list. Atlantic Pacific workers reboarded the rig the day after the storm and operations were resumed the next day.

Reference: Lloyd's List, August 15, 1989[43]

M self-elevating lift vessel *Gulf Island IV*, damaged due heavy weather. Hull section, previously stranded off Louisiana coast, has been refloated and taken to a repair yard near New Orleans and a preliminary survey has been held. The missing leg sections have been recovered and transported to the repair yard where hull repairs are being carried out.

Reference: Ocean Engineer, September 1989[44]

The jackup lift barge *AVCO 5*, which had been working for Chevron, capsized on 31 July whilst running for a safe shore haven. The vessel went down in 25 ft of water about 20 miles off Morgan City, as it was buffeted by 12 ft waves and 60 mph winds from the approaching hurricane. Although 4 of the 14 crew members were rescued, the storm prevented search vessels and helicopters from conducting a thorough search for the remaining crewmen until after the hurricane had passed. When the search began, four bodies were discovered in the living quarters, but the others could not be found.

The workover jackup rig *Ranger 6*, owned by Atlantic and Pacific Marine, was evacuated when it listed 12 degrees after pulling pipe on an Arco well in 73 ft of water in West Delta block 36 located about 100 miles south of New Orleans. The list was sufficiently steep to bring fear of capsize. (A crane barge was required to hold the unit while it was removed from location).

Hurricane ANDREW - 1992

Yr/Mo/Day	Name	Type	Comments
920827	ZAPATA SARATOGA	Semi-submersible F&G 2000	Evacuated. Mooring. broke Drifted 50 mi from Mississippi Canyon 605 to Grand Isle 47. Grounded.
920827	TREASURE 75	Semi-submersible F&G L907	Stacked. Dragged anchors; 4 mi from S. Pelto 7 to S. Pelto 8. Alleged rig tore up Texaco 20" Eugene Island 185,000 BOPD pipeline.
920827	DIAMOND M NEW ERA	Semi-submersible	Stacked in Grand Isle 103 in 255' waterdepth. Anchors may have dragged.
920827	ZANE BARNES	Semi-submersible F&G Trendsetter	Stacked. Chains broke; 167 ft waterdepth; drifted 30 mi. Aground in 35 ft. waterdepth. Allegedly knocked down Murphy platform "C" S. Timbalier 86 and did some damage to Kerr McGee satellite 2 & 3 in S. Timbalier 34
920827	PORTAL 202	Submersible	Drifted 10 mi from S. Pelto 6. Severe bottom damage. Total Loss
920827	PORTAL 201	Submersible	Drifted 10 mi from S. Pelto 6
920827	DIXILYN FIELD 77	Submersible	Slid sideways; damaged; Total Loss (low value)
920827	MARLIN 3 (SS263 Prod)	Bethlehem 265 Mat Jackup	Legs collapsed; drifted 50 mi;grounded in 17 ft. water depth; lost mat on location
920827	GLOMAR MAIN PASS IV	F & G Mod II Semi-submersible	Damaged in Ship Shoal 68; mobilized to Cameron in Oct. for repairs.
920827	JIM BAWCOM (SS 93)	Bethlehem 250 Mat Jackup	Slid 50' over wellhead; Hydril/diverter system listed; in Ship Shoal 93
920827	POOL 50	Pool Jackup	Minor damage; taken in for repairs in Oct.

920827	OCEAN KING	LeTourneau 53 Jackup	Listing ew degrees after Grand Isle 66
920827	OCEAN SUMMIT	Levingston 111C Jackup	Leaned onto Eugene Island 257C platform. Structural damage.
920827	GLOMAR ADRIATIC 2	Letourneau 116C Jack-up	Lost BOP & drive pipe at Eugene Island 255 well 7
920827	PENROD 63	LeTourneau 82SD Jackup	Structural damage originally reported. Minor electrical wire and antenna damage.
920827	ROWAN PARIS	LeTourneau 116C Jackup	One leg settled 1.5 ft. No damage
920827	DOLPHIN TITAN 106	Penn Jackup	Rig floor collapsed, derrick fell on helideck, Ship Shoal 58

Reference: Offshore Data Services Newsletter, August 31, 1992

Diamond M-Odeco's jackup *Ocean King* was reported listing severely in the Grand Isle area. The unit had been working for ARCO on Block 66. Wilrig's *Treasure 75* dragged its anchors about four miles but no damage is believed to have occurred. Some reports indicate the semi *Zane Barnes* was adrift and may have hit and seriously damaged a platform before grounding.

Reference: Offshore Rig Newsletter, Vol 19, No. 8, August 1992

By their nature, mobile offshore drilling units of every design are particularly susceptible to the effects of a major storm. Almost one half of the Gulf's 151 mobile rigs were in or near Andrew's path.

Another Diamond M-Odeco jackup, *Ocean Summit*, at first report was not on the Eugene Island Block 257 location where the rig had last been seen. The early report proved erroneous; the rig survived the storm with relatively minor damage.

Wilrig's semi *Treasure 75* went adrift during the storm and an unconfirmed report had Reading & Bates's semi *Zane Barnes* adrift also.

Reference: Offshore International Newsletter, Vol 2, No. 11, September 7, 1992

Reading & Bates semi-submersible *Zane Barnes* heads to dry dock in Sabine Pass, Texas this week for inspection and repair after sustaining hull damage in the hurricane. Extent of the rig's damage is not yet known. The semi drifted about 30 miles during the storm, apparently due to mooring chain failures. *Zane Barnes* had been "stacked ready" awaiting mobilization to Sicily in October.

Additionally, Portal Rig's drill barge *Portal 202* drifted from South Pelto Block 6 to South Pelto Block 2 during Hurricane Andrew. The jackup *Penrod 63* suffered unspecified structural damage. It also was reported that *Glomar Adriatic 2* lost its BOP stack and drive pipe.

The jackup *Dolphin Titan 106's* rig floor collapsed and the derrick fell on the rig's heliport and other equipment. As reported last week, Cliffs Drilling's mobile offshore production unit *Marlin 3* suffered a major leg failure; the hull drifted about 50 miles before grounding.

Reference: Times Picayune

A second rig, the mobile offshore drilling unit *Zapata Saratoga*, is missing and presumed sunk by the storm, the Coast Guard said. The rig, about 110 miles south of New Orleans, had been in position above a well but the well had been plugged to prevent pollution, the spokesman said. The rig had been evacuated before the hurricane moved into the area, Zapata Marine said. The storm's eye passed just south of the rig.

Reference: Houston Post

Danny Richardson, Vice President of Marketing at Zapata Off-Shore, said the *Saratoga* was recovered in Grand Isle Block 47, about 50 miles north of Mississippi Canyon Block 705 where it was located when its crew was evacuated before the storm. The rig was recovered in about 70 feet of water about 35 miles offshore and south of Fouchon, LA.

"It probably left its chain and anchors at the Mississippi Canyon location. It wasn't dragging anything," Richardson said.

Reference: Lloyd's List Sept 1, 1992

Semi-submersible drilling platform *Zapata Saratoga* arrived at Galveston today. She lost her mooring system during hurricane Andrew and sustained other damages that are considered minor.

Reference: Lloyd's List, September 1, 1992

Following hurricane Andrew, a number of platforms have been reported missing or destroyed, are unmarked and may present a hazard to navigation. Mariners should remain well clear due to the possibility of submerged debris and report sightings of the following to the United States Coast Guard: Submersible drilling barge *Portal 202*, lat 28 58 00 N, long 90 32 30 W.....

Reference: Lloyd's List, September 7, 1992

Converted jackup offshore production unit *Marlin No. 3* not on location on Ship Shoal Block 263 in lat 28 20 N, long 90 54 W, on Aug 27. Later found sunk in 17 ft water 47 miles away in South Timbalier Block 32 with legs and mats broken off.

Reference: Lloyd's List Casualty Report, September 11, 1992

Eugene Island Block 255: Self-elevating drilling platform *Glomar Adriatic II*, on well No. 7, BP stack and drivepipe missing.

Eugene Island Block 129: Jackup drilling, structural damage

Eugene Island Block 257: Jackup platform *Ocean Summit* is leaning on the "C" platform.

Grand Isle Block 47: Caisson leaning. Possibility that *Saratoga* damaged the well.

Grand Isle Block 87: Propulsion-assisted semi-submersible drilling platform *Zane Barnes* was stacked. Platform apparently broke loose. Located in South Timbalier Block 32. Platform sustained hull damage. Unit will be dry-docked at Sabine Pass in near future for inspection and repair.

South Pelto Block 7: Propulsion assisted self-elevating drilling platform *Treasure 75* was stacked in South Pelto Block 7. Platform dragged anchor and drifted for approximately four miles into South Pelto Block 8.

South Pelto Block 6: Submersible drilling barge *Portal 202* was moved to South Pelto Block 3.

South Timbalier Block 63: Self-elevating drilling platform *Ocean Pride* - small slick observed approximately 16 miles from shore.

Self-elevating drilling platform *Penrod 63* sustained unspecified structural damage. Self-elevating drilling platform *Ocean King* was thought to have sustained significant damage but has since returned to work.

Reference: Offshore International Newsletter, Vol 2, No. 12, September 14, 1992

Cliffs Drilling's mobile offshore production unit *Marlin No. 3* which was severely damaged August 25th during Hurricane Andrew in the Gulf of Mexico, was declared a constructive total loss by underwriters. The MOPU was under contract to Union Pacific Resources, which has since terminated its charter. Cliffs will receive $10 million in the third quarter from its underwriters, which will result in a $4.7 million gain. Previously, Cliffs anticipated a third quarter loss.

Reference: Offshore Rig Newsletter, October 1992

Pool Offshore's jackup *Pool 50* returned to work for Chevron following repairs to damage caused by Hurricane Andrew. As with most mobile rigs that found themselves in the path of the devastating storm, damage was relatively minor.

Global Marine's jackup *Main Pass IV* will mobilize to Cameron, Louisiana, for repair of damage sustained during the hurricane. The rig was working in the Ship Shoal area when the storm hit.

Reference: Offshore Rig Newsletter, December 29, 1992

Zapata Saratoga returned to work in the Gulf of Mexico after completion of repairs.

Winter Storm - 1983

Yr/Mo/Day	Name	Type	Comments
830120	OCEAN DRILLER	Odeco Semi-submersible	Platform adrift from her nine anchors. Drifted 50 miles.
830112	BLUE WATER 4	Santa Fe Semi-submersible	Anchor chain broke. [35]
830112	DIAMOND M NEW ERA	Semi-submersible	Anchor slipped. Rig moved 20 ft off location. [35]
830120	MR GUS 2	Bethlehem 150 Mat Jackup	Slid 2.5m off location in storm & 25' seas - lost well? BOP? [35]
830120	OCEAN TRAVELER	Semi-submersible	Slipped off location in storm & 25 ft seas. Lost wellhead & BOP [35]

A sudden storm from the Gulf of Mexico capsized boats and flooded parts of New Orleans today. Offshore winds over 80 miles an hour ripped semi-submersible drilling platform *Ocean Driller* adrift from her nine anchors. Helicopters and boats evacuated most of the crew but a 10-man standby crew remained onboard.

Reference: Lloyd's List, January 22, 1983

Three tugs were last night towing the *Ocean Driller* after it broke adrift in the Gulf of Mexico in hurricane force winds. The platform drifted for about 50 miles and all but 10 of the crew were evacuated.

APPENDIX L - References

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